Attachment 4 of 8

to Comments filed by Northern Dynasty Minerals Ltd. in Docket Number # EPA-HQ-ORD-2012-0276 – "An Assessment of Potential Mining Impacts on Salmon Ecosystems of Bristol Bay, Alaska"

THE
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PARTNERSHIP

July 23, 2012

Office of Environmental Information (OEI) Docket (Mail Code: 2822T)
Docket # EPA-HQ-ORD-2012-0276
U.S. Environmental Protection Agency
1200 Pennsylvania Ave., N.W.
Washington, DC 20460

Re: White Paper Series No. 1 – Technical and Regulatory Issues Related to Modern Mining in Alaska

Dear Sir or Madam:

The U.S. Environmental Protection Agency ("EPA") recently released a draft report titled "An Assessment of Potential Mining Impacts on Salmon Ecosystems of Bristol Bay, Alaska" (the "Assessment"). The Assessment relies on an array of uninformed and inaccurate statements that ignore environmental standards of best practices and modern engineering design. Further, it neglects to take into account the extensive mitigation measures that will be implemented to offset potential impacts from mining – measures that must be reviewed and approved during the rigorous Clean Water Act Section 404 permitting process and associated reviews pursuant to the National Environmental Protection Act, Endangered Species Act, and other federal and state regulatory programs. For these and other reasons, the environmental and habitat impacts described in the Assessment have been grossly overstated.

Purpose and List of Technical Papers

The Assessment is based almost completely on assumptions and hypothetical scenarios; however, every mine is very different in terms of its design and operations. In addition, EPA appears to have focused almost exclusively on past mine failures in its Assessment rather than on mine successes, particularly those currently operating under modern engineering design standards. This approach suggests an inherent bias in EPA's Assessment that undermines its utility and would certainly lead to arbitrary and capricious agency action if the information contained in the Assessment is used in support of future decision-making.

Due to the Agency's reliance on uninformed assumptions, disregard for current mine practices and neglecting required mitigation measures, the attached collection of technical papers is intended to serve as a primer on some of the basic principles of current mine development within the regulatory and permitting framework in Alaska. It is clear that EPA lacks that basic understanding. The white paper series therefore has two primary objectives: (1) to share knowledge of key technology issues related to modern mine design and mitigation options; and (2) to provide additional scientific citations for consideration as part of the Assessment.

The list of the technical papers and associated lead companies included as White Paper Series Number 1 is provided below.

No.	Title of Paper	Company
1	Mitigating Risk in the Design and Construction of Tailings Dams in Alaska	Knight Piesold
2	Development of Stable Waste Rock Piles in Alaska	Knight Piesold
3	Active Metal Mines of the Fraser River Basin and Fish – Case Studies	Knight Piesold
4	Fraser River Salmon and Mining Review	AECOM
5	Offsetting Potential Wetlands Impacts through the Environmental Permitting Process	HDR, Inc.
6	Summary Review of Fish Habitat: Flow Dependencies and Methods for Evaluating Flow Alteration Effects	R2 Resource Consultants
7	Aquatic Habitat and Fish Population Recovery in the Toutle River following the 1980 Eruption of Mount St. Helens	R2 Resource Consultants

Overview of White Papers

WP No. 1 - Mitigating Risk in the Design and Construction of Tailings Dams in Alaska

This paper summarizes the regulatory process of the Alaska Dam Safety Program (ADSP), which is the central governing body responsible for dams in Alaska. The intent of the paper is to provide some background information regarding the requirements to construct a dam in Alaska, and to provide information regarding oversight and corporate responsibility as it relates to dam construction and operation. It is important to note that tailings dams for large-scale mining operations are major structures that have been constructed, operated and closed successfully in many parts of the world. The success and long-term stability of these structures are greatly enhanced by adherence to strict regulatory requirements. The current state-of-the-art practice for tailings dam design and operations incorporates lessons learned from the analysis of past tailings dam failures and the successful performance of other large dams and tailings embankments. Some key findings as presented in the paper include the following:

- The performance of tailings dams constructed by the centerline or downstream methods has been markedly better than dams constructed by the historically common upstream method. Accordingly, downstream and centerline constructed tailings dams are the current preferred methods of construction.
- Tailings dams can be built to stand indefinitely provided the right procedures, protocols, checks and monitoring are in place throughout all phases of a dam life, including design, construction, operation, closure, and post closure.
- Embankments constructed with compacted earthfill and rockfill materials have a proven performance record during seismic loading conditions.
- Large embankment dams have a proven performance of successful operation for a variety of extreme events, such as very cold weather conditions, extreme floods, and large earthquakes.

- The comprehensive ICOLD records do not include any instances in the world reflecting failure of a large tailings dam; i.e., over 500 feet in height.

WP No. 2 - Development of Stable Waste Rock Piles in Alaska

This paper presents an overview of the design, construction, and operation methods for the development of stable waste rock piles, with a discussion of cold region and other specific considerations relevant to the Bristol Bay region.

Waste rock piles are developed to store non-economic rock and overburden materials for open pit mining operations. Waste rock piles are potentially large structures that are progressively constructed during mine operations in accordance with relevant Alaska statutes, regulations, and guidelines. Well established investigation methods, design procedures, operating requirements, and monitoring practices have been developed on the basis of experience at other large mining operations in North America. Some of the key considerations for the development of stable waste rock piles at Alaska mines are summarized in the paper, along with requirements for establishing stable permanent reclaimed landforms after mine closure.

WP No. 3 - Active Metal Mines of the Fraser River Basin and Fish – Case Studies

Mining has a long history in the Fraser River Basin starting with the Cariboo Gold Rush in the 1850s. Similar to the Bristol Bay Watershed, the Fraser River is among the world's most productive salmon rivers and supports commercial, recreational, and subsistence fisheries. Due to its long history, mining has historically been met with some concern with respect to fisheries conservation due to potential negative effects to the land base, water quality, water quantity, and fish habitat. Those concerns, however, can be addressed through modern mine design and construction.

This paper presents case studies from four active metal mines in the Fraser River watershed as a means to assess the risk of mining operations to fisheries. Information concerning mine engineering, operating details, and environmental setting are identified and assessed for this purpose. While these mines have some minor localized effects to fish and fish habitat, there is no evidence to suggest these mines present a current or future risk to the fishery resources of the overall Fraser River watershed. The four active metal mines assessed in this white paper are all examples, with proven track records, of sustainable low impact operations adjacent to important fish habitat in the Fraser River drainage.

WP No. 4 - Fraser River Salmon and Mining Review Update through 2010

This paper provides a review and summary of the existing data on salmon stocks and resource development within the Fraser River watershed with a focus on evaluating the effects of mining activities on the watershed. Although the Fraser River watershed is an urbanized ecosystem and is subject to multiple influences, it still supports a robust commercial, native and recreational salmon fishery. As such, the Fraser River can provide valuable lessons for development within Bristol Bay.

In fact, it is highly unlikely that the Bristol Bay watershed will ever see the population level and degree of urban and industrial development that is present in the Fraser River watershed. This means that with proper management of resources and development, the Bristol Bay watershed can continue to support healthy salmon runs while supporting other resource developments that will further enhance the economic potential of the region. In fact, development within the Bristol Bay watershed would have the benefit of more sophisticated planning and knowledge of prior resource development in other regions. With that sophisticated planning, sustainable development within the watershed can be ensured, such that development (including mining) today won't compromise the health and balance of future salmon populations within the overall watershed.

WP No. 5 - Offsetting Potential Wetlands Impacts through the Environmental Permitting Process

The hypothetical scenario developed for the Assessment failed to take into consideration any potential mitigation measures that would offset predicted potential impacts from large scale mining in the Bristol Bay watershed. This failure is striking. Throughout Alaska, there are numerous important development projects currently being planned, including mines, renewable energy sources, oil and gas facilities, and public infrastructure. Mitigation will be relevant to each and every one of those developments.

The purpose of this white paper is to summarize various approaches for offsetting potential impacts on wetlands and related water bodies. Wetlands are ubiquitous in Alaska and most development projects will be required by law to have mitigation plans to offset unavoidable impacts to wetlands. Thus, this paper focuses on the regulatory requirements and mitigation options for projects in Alaska and provides examples of possible compensatory mitigation opportunities that could result from mining and other development in the Bristol Bay region.

Any resource development project in Alaska will have to go through a thorough and complex permitting process. This process incorporates specific requirements to ensure that each project addresses potential impacts to wetlands resources, including a wetlands mitigation plan, closure and reclamation plan, and payment of bonds for financial assurance for closure throughout the life of the project. Through this process, the co-existence of important development projects and protection of valuable ecosystem services can be obtained.

WP No. 6 – Summary Review of Fish Habitat: Flow Dependencies and Methods for Evaluating Flow Alteration Effects

The method EPA used for judging the degree of impact on salmonid populations in the Assessment is essentially hydrologically-based and has no direct linkage to actual salmonid fish populations and salmonid fish habitat in the watershed. In fact, EPA's statements regarding flow reduction effects on salmonid populations are unsupported by the published literature; the Assessment therefore fails to apply the "best available science" regarding this critical issue.

Many states, including Alaska, have long recognized the importance of their fishery resources, both from a recreational and commercial perspective and as a trust resource for tribal interests.

As such, those states have focused on ensuring sufficient streamflows to maintain population viability. Programs for defining instream flow needs to protect such resources have been implemented in many states (including Alaska, Washington, Oregon and others) using a variety of methodologies.

The purpose of this paper is to address EPA's lack of sound science in its evaluation of flow reduction and fish resources in the Assessment by providing a technical review of: 1) the importance of streamflow on fish and aquatic habitats in streams; 2) the methods and models that are currently used to assess the effects of flow regulation on fish habitats; and 3) key case studies where flow regulation was an issue. The paper reviews the specific methods employed in those case studies in developing instream flow release schedules designed to protect aquatic resources and mitigate for potential flow modifications resulting from project development.

This paper demonstrates the importance of flow to the functionality of various fish life stages and that flow regulation can have significant biological impacts on fish and aquatic resources depending on a number of factors, including the type, magnitude, timing, and duration of the flow regulation. Fortunately, there are a variety of methods and models that have been developed that can help to understand and define these effects and provide guidance in formulating instream flow prescriptions designed to protect, mitigate for and even enhance habitat conditions. The case studies described in the paper provide real-world examples of where and how the impacts associated with flow regulation on fish habitats have been successfully addressed. In all cases, the key ingredients leading to success include the careful design of studies and application of sound scientific methodologies for identifying and quantifying impacts and deriving appropriate instream flow measures.

WP No. 7 - Aquatic Habitat and Fish Population Recovery in the Toutle River following the 1980 Eruption of Mount St. Helens

The Assessment uses the eruption of Mount Saint Helens as an analogy to a tailings dam failure. This is a completely unrealistic and unscientific analogy to large scale mining in the Bristol Bay watershed.

However, having an adequate understanding of aquatic habitat and fish population recovery and the inherent components and processes contributing to recovery of such an ecosystem is important. With that objective in mind, this paper provides a review of Toutle River ecology in the wake of the 1980 Mount Saint Helens' eruption. Although the Toutle River aquatic habitat experienced extensive damage with entire headwater tributaries and localized fish populations lost, recovery processes began soon after the perturbation and within a few years habitats and aquatic populations had started to rebound. Processes contributing to the recovery of the river ecosystem included:

- Flushing flows that moved unimpeded sediments downstream and cleaned out spawning gravels.
- Aquatic microbes that utilized new sources of nutrients provided from tree fall and ash deposits, which established new trophic regimes.
- Seed banks that supported reestablishment of riparian communities which in turn contributed to improved water quality.

It was the complexity and behavioral plasticity inherent to the Toutle River fish populations that facilitated population recovery. The ongoing recovery of the Toutle River has provided a living laboratory for understanding aquatic system recovery and highlights the processes inherent to natural aquatic systems that support persistence in an unpredictable environment while demonstrating the resiliency of natural systems.

Summary

The collection of white papers included in this series address various technical and regulatory issues related to tailings design, waste rock pile design, mining co-existing within other important salmon watersheds, wetlands mitigation, and inherent ecosystem resiliency in response to perturbation or disturbance. All of these issues are critical scientific foundations to be considered in any type of environmental assessment related to resource development.

We would be willing to confer or answer any questions that you may have regarding these white papers. For your information, Pebble will be preparing a second white paper series on additional scientific and technical topics in the future and will be happy to share those with EPA when they are available.

Sincerely,

John Shively
Chief Executive Officer

Attachment – White Paper Series No. 1

White Paper Series No.1 - Technical and Regulatory Issues Related to Modern Mining in Alaska

Submitted to USEPA in response to:

Docket ID No. EPA-HQ-ORD-2012-0358

An Assessment of the Salmon Ecosystem in Bristol Bay, AK - External Draft Review, May 2012

July 23, 2012

THE pebble PARTNERSHIP

Acknowledgements

This Technical Paper series No. 1 was produced in response to the release of EPA's draft report titled *"An Assessment of the Salmon Ecosystem in Bristol Bay, AK."* Pebble Limited Partnership would like to thank the authors for their contributions to the technical work contained within this collection. The authors were selected for their expertise and unparalleled reputations in the subject matter addressed in this collection. Their dedication to their profession and their commitment to producing top quality scientific products is recognized and appreciated at local, national and international levels.

A full version of this White Paper series is available on the Pebble Project website: www.pebbleresearch.com

Photo Credits: Cover photographs provided Courtesy of Anglo American

Photo 1: Las Tortolas tailings impoundment - Chile

Photo 2: Las Tortolas tailings dam - Chile

Photo 3: Tortolas Pond – Chile

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Attachment 1
Mitigating Risk in the Design and Construction of Tailings Dams in Alaska

White Paper No. 1
Topic: Tailings Dams
Title: Mitigating Risk in the Design and Construction of Tailings Dams in Alaska
Authors: Jeremy P. Haile, P.E. and Ken J. Brouwer, P.E.

Abstract

Tailings dams for large-scale mining operations are major structures that have been constructed, operated and closed successfully in many parts of the world. The success and long-term stability of these structures are greatly enhanced by adherence to strict regulatory requirements, which in Alaska are dictated and governed by the Alaska Dam Safety Program. The current state-of-the-practice for tailings dam design and operations incorporates lessons learned from the analysis of past tailings dam failures and the successful performance of other large dams and tailings embankments. A key conclusion of these analyses is that the performance of tailings dams constructed by the centerline or downstream methods has been markedly better than dams constructed by the historically common upstream method. Additionally, embankments constructed with compacted earthfill and rockfill materials have a proven performance record during seismic loading conditions. There are relatively few incidences of dam instability for downstream and centerline constructed tailings dams and none of these instances include dams exceeding 500 ft in height. Accordingly, downstream and centerline constructed tailings dams are the current preferred methods of construction .

It is important to note that it is incorrect to imply that any particular proposed or actual dam structure is more or less likely to fail based solely on the extrapolation of general dam failure statistics. The integrity and stability of any dam structure should rather be ascertained by suitably qualified and competent professionals, whose assessment must take into consideration all relevant aspects of the specific site conditions and facility details. Finally, the success of a tailings dam project is enhanced by a strong, accountable owner with a stated commitment to build and operate a facility in a socially, environmentally, and ethically responsible manner.

These topics are presented along with a discussion of some of the key site-specific factors at the Pebble Project, and an overview of design and construction approaches to successfully mitigate the risks related to slope stability, overtopping, foundation conditions, seepage, erosion, earthquakes, extreme climatic/hydrologic conditions, and complacency.

1. Introduction

Tailings dams for major mining operations are among the world's largest man-made structures. Tailings dams have been constructed, operated and closed successfully, even after being subjected to extreme events, including major earthquakes and flood events. However, there are some instances where tailings dam failures have occurred, with failure or breaching being '*a collapse or movement of a part of the dam or its foundation so that the dam cannot retain the stored water*',[1] or with regards to tailings dams, the stored water and tailings.

Analyses of both the successful performance and the failure of tailings dams are important in providing input on the design and operating criteria of new tailings dams. The root causes of failure, and the mechanisms of failure, have been extensively studied from case histories. Much of the analyses of water and tailings dam failures have been carried out by the International Commission on Large Dams (ICOLD), who have stated that *'many factors influence the behavior of tailings impoundments; accidents and other incidents are often the result of inadequate site investigation, design, construction, operation, or monitoring of the impoundment, or a combination of these. Every site and dam is unique so direct application from one to another is seldom possible. However, there are a number of common principles and the lessons learned from incidents at one dam can be applied in general terms to other situations .'*[2]

This paper summarizes the regulatory process of the Alaska Dam Safety Program (ADSP), which is the central governing body responsible for dams in Alaska. The intent is to provide some background information regarding the

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[1] International Commission on Large Dams (ICOLD). 1995, Tailings Dams and Seismicity, Bulletin Number 98.
[2] International Commission on Large Dams (ICOLD). 2001. Tailings Dams Risk of Dangerous Occurrences, Lessons Learnt from Practical Experiences. Bulletin Number 121.

requirements to construct a dam in Alaska, and to provide information regarding oversight and corporate responsibility as it relates to dam construction and operation. A discussion of lessons learned from past dam failures and from successful performances is considered, including instances when the dams have been subjected to extreme conditions. The precedent for constructing large water and tailings dams throughout the world is presented in terms of height, location and year of construction or planned construction. Site specific considerations for constructing stable dams at the Pebble Project are identified along with a discussion of how each consideration can be mitigated through prudent and appropriate design, independent review, construction supervision, and monitoring.

Tailings dams for any project in Alaska will be expected to be designed and constructed to the highest standards, as required by a strict regulatory process that is already in place through the Alaska Dam Safety Program; by the use of appropriate hazard classification processes to assign appropriately conservative design criteria; and by corporate commitments for meeting or exceeding all regulatory requirements. State-of-the-practice engineering design methods will be applied along with appropriate construction methodologies, coupled with regulated requirements for oversight and quality control. Tailings impoundments for any such project will be designed, constructed and operated to achieve and maintain performance objectives and to form stable long-term landforms in perpetuity. Dam safety inspections, on-going monitoring and regular reviews will continue well after mine closure to ensure that these objectives are satisfied.

2. The Alaska Dam Safety Program

The Alaska Dam Safety Program (ADSP) is administered by the Alaska Department of Natural Resources (ADNR) in cooperation with other agencies, stakeholders and involved parties. The ADSP's Mission is '*…to protect life and property in Alaska through the effective collection, evaluation, understanding and sharing of the information necessary to identify, estimate and mitigate the risks created by dams*'.[3] The ADSP has prepared guidelines to establish a consistent basis for communication between ADNR, dam owners and operators, and other entities involved in the planning, design, construction, operation and regulation of dams in Alaska.

An overview of the ADSP guidelines is provided in two sections below. The first section summarizes the dam hazard classification system in Alaska, demonstrating how the hazard classification is determined and how the seismic and hydrologic design specifications are assigned. The second section focuses on the dam approval and certification process, illustrating the steps required to sanction dam construction, operation, and closure.

2.1. Hazard Classification of Dams

Many jurisdictions throughout the world now use hazard classification systems to define the dam class or risk associated with a dam. This generally applies to all dams that are over a certain height and/or retain a certain volume of water. The dam class is then used to define the appropriate return period (probability of occurrence – for example, a 100 year return period event has a probability of occurring once in 100 years, on average) for the design earthquake event and the inflow design flood. Higher hazard class dams, which are those with a potentially high impact if they fail, are required to be designed to more stringent standards and required to withstand more extreme or unlikely design events. Basically, the greater the consequences of failure, the higher the standard of care required. The hazard classification system in Alaska is defined by the ADSP Guidelines and is shown in Table 1.

The ADSP hazard potential classifications are consistent with the *Federal Guidelines for Dam Safety: Hazard Potential Classification for Dams*, published by the Federal Emergency Management Agency (FEMA). '*The hazard potential classification determines the standard for the design, construction and operation of the dam during the life of the project*'.[4]

[3] Alaska Department of Natural Resources. 2005. Guidelines for Cooperation with the Alaska Dam Safety Program. *Dam Safety Construction Unit, Water Resources Section, Division of Mining, Land and Water.*
[4] Federal Emergency Management Agency (FEMA) 1998. Federal Guidelines for Dam Safety: Hazard Potential Classification for Dams.

Table 1 – Hazard Potential Classification Summary[3]

Hazard Class	Effect on Human Life	Effect on Property
I (High)	Probable loss of one or more lives	Irrelevant for classification, but may include the same losses indicated in Class II or III
II (Significant)	No loss of life expected, although a significant danger to public health may exist	Probable loss of or significant damage to homes, occupied structures, commercial or high-value property, major highways, primary roads, railroads, or public utilities, or other significant property losses or damage not limited to the owner of the barrier Probable loss of or significant damage to waters identified under 11 AAC 195.010(a) as important for spawning, rearing, or migration of anadromous fish
III (Low)	Insignificant danger to public health	Limited impact to rural or undeveloped land, rural or secondary roads, and structures Loss or damage of property limited to the owner of the barrier

2.1.1. *Design Earthquake Event*

The ADSP Guidelines require that two levels of design earthquake be established as follows:

- Operating Basis Earthquake (OBE): *'The OBE is an earthquake that produces ground motions at the site that can reasonably be expected to occur within the service life of the project. The associated performance requirement is that the project functions with little or no damage, and without interruption of function. The purpose of the OBE is to protect against economic losses from damage or loss of service. Therefore, the return period for the OBE may be based on economic considerations.'*[5]
- Maximum Design Earthquake (MDE): *'This is the earthquake that produces the maximum level of ground motion for which a structure is to be designed or evaluated. The MDE may be set equal to the MCE* (Maximum Credible Earthquake) *or to a design earthquake less than the MCE, depending on the circumstances. Factors to consider in establishing the size of MDE are the hazard potential classification of the dam. In general, the associated performance requirement for the MDE is that the project performs without catastrophic failure, such as uncontrolled release of a reservoir, although significant damage or economic loss may be tolerated.'*[5]
- For reference, the MCE is defined as *' the largest earthquake magnitude that could occur along a recognized fault or within a particular seismotectonic province or source area under the current tectonic framework.'*

The ADSP Guidelines recommend a range of probabilistic return periods considered appropriate for defining the OBE and the MDE, as a function of the hazard potential classification of the dam, as shown in Table 2.

Table 2 – Operating and Safety-Level Seismic Hazard Risk[3]

Dam Hazard Classification	Return Period, Years	
	Operating Basis Earthquake	Maximum Design Earthquake
I	150 to >250	2,500 to MCE
II	70 to 200	1,000 to 2,500
III	50 to 150	500 to 1,000

Seismic studies for the design of a new dam would proceed with the definition of the design earthquake at the site for appropriate OBE and MDE events. The seismic design parameters associated with the selected design earthquakes,

[5] Federal Emergency Management Agency (FEMA) 2005. Federal Guidelines for Dam Safety, Earthquake Analysis and Design of Dams.

including peak ground acceleration and earthquake magnitude, would then be used to assess the performance of the proposed dam design in response to the earthquake loading.

2.1.2. *Inflow Design Flood*

The Inflow Design Flood (IDF) is the primary input of the hydrological portion of the design. The IDF in Alaska is defined as '*the flood flow above which the incremental increase in the downstream flood caused by a failure of the dam does not result in any danger downstream*.[3] The IDF typically ranges between the 1 in 100 year 24-hour storm flood and the Probable Maximum Flood (PMF), depending on the dam classification. A PMF is defined by the ICOLD as '*the flood that may be expected from the most severe combination of critical meteorological and hydrologic conditions that are reasonably possible in the drainage basin under study*'. A PMF is generated from the probable maximum precipitation (PMP), which is defined by ICOLD as '*theoretically, the greatest depth of precipitation for a given duration that is physically possible for a given size storm area at a particular geographic location at a certain time of year*'. For Alaska, most PMF determinations incorporate a snowmelt component to account for the possibility of the PMP occurring in conjunction with a significant snowpack.

2.2. Regulatory and Permitting Process

The ADSP Guidelines outline the steps and submission requirements for designing, constructing, operating, modifying and closing a dam in Alaska. The ADSP provides all stakeholders with reassurance that all the correct steps in the design, construction, operation and closure of dams will be implemented by specifying the responsible parties and their responsibilities, the qualifications required for dam design, construction and inspection, and the certificates required for approvals.

The ADSP defines the responsible parties as follows:

- Alaska Statute (AS) 46.17.020 requires ADNR to employ a professional engineer to "supervise the safety of dams and reservoirs" in Alaska. The State Dam Safety Engineer is responsible for administering the ADSP.
- Dam Owners are responsible for mitigating the risks created by each dam by developing all necessary policies, plans and procedures, providing all required funding, hiring suitably qualified personnel to manage and operate the dam, retaining suitably qualified engineers and contractors to design and construct the dam, and ensuring the quality and success of the overall project.
- A Qualified Engineer, as defined in the Alaska dam safety regulations, is required to assure that the dam is designed, built and operated with appropriate concerns for safety. The Qualified Engineer must be a civil engineer currently licensed to practice in Alaska.

All dams require Periodic Safety Inspections (PSI) by a Qualified Engineer. A PSI is required every 3 years for a Class I or Class II dam. Performance and incident reporting is also required following any significant event; the guidelines prescribe what types of incidents need reporting based on hazard classification. All events classified as seismic, hydrologic, failure or breaching, deterioration, mis-operation, or activation of the Emergency Action Plan (EAP), require reporting for a Class I or Class II dam.

Various certificates for approvals are required at different stages of design, construction, operation, and closure including:

- Certificate of Approval to Construct a Dam
- Certificate of Approval to Operate a Dam
- Certificate of Approval to Modify a Dam
- Certificate of Approval to Remove a Dam, and
- Certificate of Approval to Abandon a Dam.

The ADSP Guidelines outline the detailed steps and submission requirements to be followed for the application of each certificate. ADSP staff will hire external specialist engineers to assist with the reviews and will review and approve all designs before any of the above certificates can be issued.

Operation and Maintenance (O&M) and Emergency Action planning are the most important aspects of an owner's commitment to dam safety. ADSP staff will only issue a Certificate of Approval to Operate a Dam after an O&M Manual and an EAP are submitted by the Dam Operator. The O&M Manual will include, among other things:

- Critical design criteria
- Schedules for safety inspections, monitoring, and maintenance
- Instructions for monitoring equipment, and
- Site specific visual check-lists.

The EAP will detail all actions and measures that will be taken in response to an emergency.

Tailings dams are normally constructed in stages over the operating life of the facility and thus the O&M Manual will need to include an overall filling schedule for the tailings dam, and a schedule for construction of each embankment raise. Each embankment construction stage will require a new application to receive a Certificate of Approval to Modify a Dam. The required submissions and review steps are similar to the application for a new dam, but the review schedule may be shorter, as much of the information would have already been reviewed.

Closure requirements for a tailings dam are typically addressed in the mine reclamation plan. Construction of the final closure measures will require new applications to receive a Certificate of Approval to Abandon a Dam or a Certificate of Approval to Remove a Dam. The required submissions and review steps will be similar to previous applications; bonding will likely be required, together with approval of on-going O&M requirements for closed out dams.

3. Oversight and Corporate Responsibility

The correct use of existing design guidelines available for dam construction is paramount to overall dam success. Correct design from the conception of the project is a principle factor in ensuring the safety and stability of the dam. With reference to designing dams in the United States of America, multiple design standards are available to aid in developing the correct design approach including publications by: U.S. Army Corps of Engineers, U.S Bureau of Reclamation, U.S. Department of Agricultural, Natural Resources Conservation Service, Federal Emergency Management Administration, Federal Energy Regulatory Commission, U.S. Society on Dams and American Society of Civil Engineers. This list is by no mean exhaustive but serves to show that a wealth of information is available to facilitate the initial stages of dam design and ensure that it is conducted according to accepted industry standards. As mentioned above, the identified key design parameters and issues highlighted in the initial investigations for any given site must be incorporated into the design process at an early stage.

Dam designs are subject to peer review as part of the Alaska Dam Safety Program in order to evaluate the competence of the program relative to the generally accepted standards of practice for dam safety. Multiple individuals and organizations can be invited to participate in the peer review process, with the overall goal to provide professional guidance to dam safety programs to improve design and management.

The Alaska Dam Safety Program ensures the controlling body is kept informed throughout the life cycle of the project. However, emphasis is normally placed on the Owner to ensure that construction occurs in accordance with the original design parameters. This is achieved by use of Construction Quality Assurance/Quality Control (CQA/QC) plans to ensure that the dam technical specifications and construction guidelines are met. Additionally, Post Construction Submittals detailing the construction record, including any modifications, tests, and inspections undertaken, are conducted to ensure the Owner's compliance with the design. This is particularly important as tailings dams are progressively constructed during operations; the dam undergoes subsequent lifts throughout the life cycle of the project to achieve the final design height.

Closure must be planned at an early stage to allow for sufficient funding to be pre-allocated for the final closure plan to be fully implemented, which will most likely occur when all revenue streams from the mine operations have ceased. To this effect, it is common for a financial surety or bond to be lodged with a third party so that sufficient funding is available for a proposed closure plan. It is also a prerequisite of the current ADNR legislation governing tailings dam permits to request that a bond be lodged and a closure plan be submitted during the permitting stage.

International standards require that the following aspects be incorporated as part of closure planning:

- *'The engineering aspects and long term surveillance of the scheme in order to address long term stability and safety,*

- *Environmental controls to avoid groundwater contamination from seepage arising from stored residues, or air pollution from dust, or hazardous emissions, and*
- *Some form of rehabilitation plan to take place on completion of the scheme or as part of an ongoing restoration program...'.*[6]

It is advantageous to consider closure during each phase of both the dam design and the tailings facility layout, since it is significantly more economical to incorporate closure measures directly into the design than it is to retrofit them after mine operations.

Finally, the success of the regulatory oversight process, and ultimately the success of the tailings dam, is enhanced by having a strong, accountable owner with a stated corporate commitment to build and operate a facility in a socially, environmentally, and ethically responsible manner.

4. Design and Construction Approaches to Mitigate Risk

Large tailings dams are typically constructed in stages to reduce upfront capital costs and to facilitate on-going adjustments to the design in order to adapt to changes in mine throughput and total tonnage of tailings deposition as mining progresses. The design of tailings dams is generally carried out by developing the final concept first to satisfy the overall tailings storage requirements and closure design objectives. Detailed design of the initial stages is then carried out; but the design of subsequent stages can be adjusted to accommodate changes to the mine throughput, changes to the water management system, variations in embankment construction materials from the parameters used in the initial design, and any other unforeseen conditions that would result in changes to the construction requirements. These changes can be incorporated into the dam design while it is being constructed to ensure that the ultimate objectives will be met.

The successful design, construction, operation and closure of a tailings dam requires a good understanding of the complete life cycle of the facility. With this understanding, and by following a carefully developed program to define all site and material characteristics, appropriate decisions can be made with respect to the detailed design of all components of the facilities in order to mitigate risk. The key steps in the process of the design include:

- Summarize the regulatory framework and relevant laws under which the tailings dam will be permitted.
- Determine the hazard classification of the dam, and select the appropriate design earthquake and inflow design flood.
- Evaluate the regional seismicity for the select the appropriate seismic design parameters.
- Complete initial siting studies to guide the site investigations.
- Confirm the design basis and governing parameters that will be relevant to the design.
- Site characterization with respect to climate and hydrology, both surface water and groundwater, regional geology, terrain hazards and seismicity.
- Waste characterization of the tailings solids, including geotechnical properties, and geochemical characteristics such as acid generating potential and metal leaching characteristics.
- Chemical characterization of the aqueous portion of the tailings slurry.
- Evaluate design options including consideration of alternative tailings technologies such as; conventional slurry tailings, thickened tailings, paste tailings and filtered tailings.
- Select the preferred embankment construction type.
- Detailed site investigations to define foundation and groundwater conditions.
- Identify potential construction materials and conduct suitable laboratory testing.
- Geotechnical design of the tailings embankment and management facility.
- Preparation of a Closure Plan.
- Preparation of a site-wide water balance model and design of the overall water management system.
- Preparation of the Operations and Maintenance manual and an Emergency Action Plan.

The above steps all contribute to the development of a safe and reliable tailings management system.

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[6] International Commission on Large Dams (ICOLD). 1996. A Guide to Tailings Dams and Impoundments – Design, construction, use and rehabilitation. Bulletin Number 106.

Tailings embankments are typically constructed using tailings, waste rock or borrow materials. Mine overburden and waste rock are often used if the tailings storage facility is close to the mine site, and borrow materials may be utilized if the tailings or waste rock are unsuitable. Construction materials can be classified as unsuitable if the permeability, compressibility, shear strength parameters, and geochemistry do not meet required specifications. Tailings embankments are generally constructed in stages as the tailings solids are accumulated within the impoundment. Thus, the staged development of the facility allows for considerable flexibility to incorporate modifications to the design and construction of the embankment throughout the life of the mine.

It is also noted that although tailings dams and water dams share a considerable amount of similarity in design and construction, they are two very different structures. The technology of tailings dam design is based on the same principles as water dams; however, the presence of saturated tailings solids as the stored medium, versus water only, presents unique challenges and design considerations. For instance, impounded tailings solids have hydraulic conductivity and shear strength properties that can be used to the advantage of the designer.[7] Furthermore, the primary purpose of a tailings impoundment containment structure is to provide a stable embankment for the secure retention of normally consolidated tailings solids, as opposed to a more conventional dam structure, which is designed and operated to provide secure containment of a fluid reservoir. The long term post closure objective for a tailings impoundment usually involves transitioning the solids retention facility into a stable landform, whereas the final closure plan for a water dam would typically involve dam removal.

4.1. Tailings Embankment Construction Methods

The construction of a tailings embankment is typically undertaken in a staged manner over the period of time that tailings deposition is under way. Under this approach, there are three principal construction methods for raising the embankment crest during the staged expansion of a tailings facility: upstream, centerline, and downstream, all of which involve sequentially raising the embankment as the impoundment fills with tailings solids over the life of the mine.

4.1.1. Upstream Construction Methods

The upstream construction technique has been used extensively for many tailings embankments worldwide, largely because of the relatively low construction costs associated with this method. A simplified section of a tailings dam using the upstream construction method is shown on Figure 1. The upstream construction method typically incorporates a relatively smaller zone of compacted structural fill within the embankment and relies on uncompacted hydraulically placed tailings as a foundation material for the on-going embankment raises.

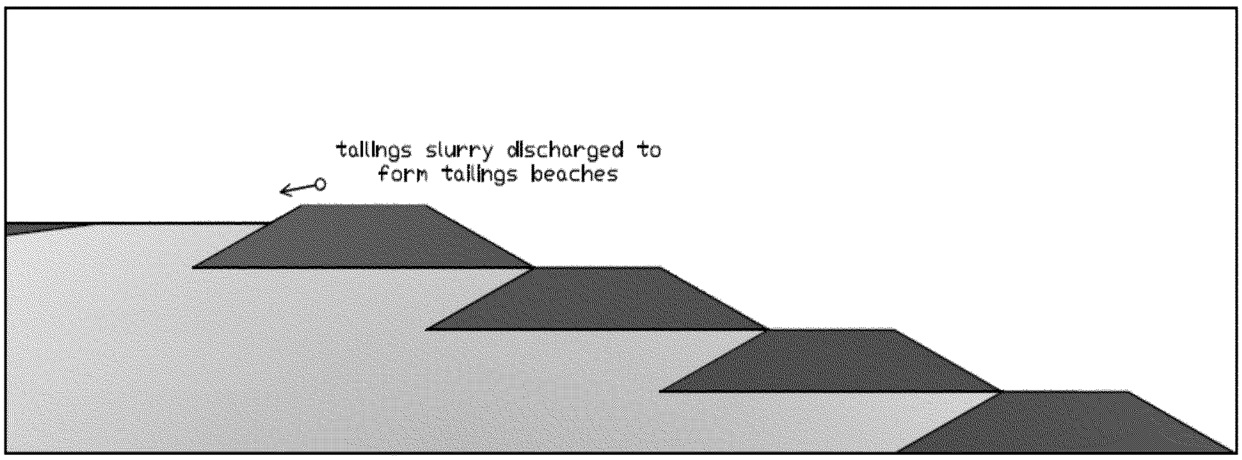

Figure 1 – Upstream Tailings Embankment Construction Method

[7] McLeod, H. and Murray, L. 2003. Tailings Dam versus a Water Dam, What is the design difference? ICOLD Symposium on Major Challenges in Tailings Dams, June, 2003 *http://www.infomine.com/publications/docs/McLeod2003b.pdf*

The exposed tailings solids adjacent to the embankment ('tailings beach') must form a competent foundation for the support of the next embankment lift. As a general rule, the tailings slurry discharged from the embankment crest should contain sufficient sand sized particles in order to develop a suitable tailings beach.[8] Thus the upstream method is very dependent on the geotechnical characteristics of the tailings materials generated by the mineral extraction processes in the mill circuit. Other limiting factors include phreatic surface control, water storage capacity, seismic liquefaction susceptibility , and the rate of dam raising.

The location of the phreatic surface (or water table) within the tailings beach is an important stability consideration and is dependent on: the permeability of the foundation relative to the tailings, the degree of grain-size segregation, the lateral permeability variation within the deposit, and the location of ponded water relative to the embankment crest.[8] A relatively rapid rate of rise of the tailings solids can result in the development of excess pore pressures within the tailings deposit due to incomplete drainage and consolidation. This build-up of pore pressures results in lower shear strength for the tailings materials and can lead to shear failure when the upstream construction method is used.[9] The upstream construction method is prohibited in Chile due to concerns over the seismic stability of the structures.[10] Implementation of conventional upstream construction methods is generally not appropriate in Alaska due to similar concerns relating to the high seismicity of the region.

4.1.2. Centerline Construction Method

The centerline embankment construction method typically utilizes a comparatively wider zone of compacted structural fill and does not rely on uncompacted hydraulically placed tailings for embankment stability during on-going staged expansion of the tailings facility. A simplified section of a tailings dam using the centerline construction method is shown on Figure 2.

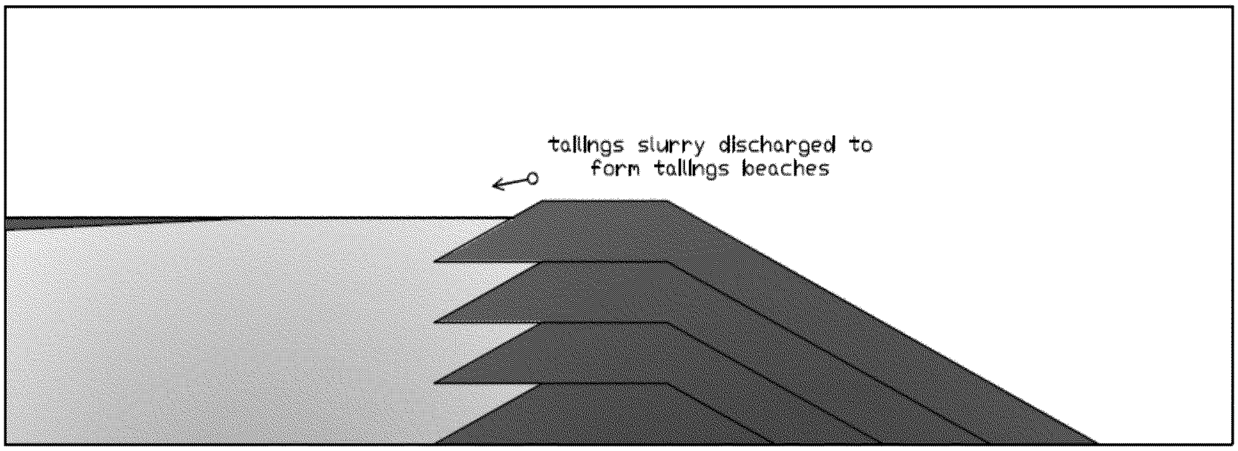

Figure 2 – Centerline Tailings Embankment Construction Method

The centerline construction method is a well-accepted and widely used construction technique that results in an inherently stable structure that does not rely on the strength of the deposited tailings solids. It is often selected because of its superior seismic and static stability as compared to upstream construction methods, and has reduced embankment quantities and a smaller foundation footprint when compared to downstream construction methods. A properly compacted centerline embankment with good internal drainage is resistant to seismic activity. Even in the event that the tailings along the upstream slope liquefy, the central and downstream portions of the dam remain stable due to their good compaction and drainage characteristics.[11]

[8] Vick, SG 1990. Planning, Design and Analysis of Tailings Dams. *BiTech Publishers Ltd.*
[9] Brawner, CO and Campbell, DB. 1973. The Tailings Structure and its Characteristics - A Soil's Engineer's Viewpoint. *Tailings Disposal Today, Proceedings of the First International Tailings Symposium, Tucson, Arizona, October 31, November 1, 2 and 3, 1977.*
[10] Government of Chile. 2007, Diaro Oficial de la Republica de Chile, page 10, Article 14, paragraph (h).
[11] Environmental Protection Agency, (EPA) 1994. Design and Evaluation of Tailings Dams. *U.S. EPA, Office of Solid Waste, Special Waste Branch, 401 M Street, SW, Washington, DC 20460.*

4.1.3. *Downstream Construction Method*

The downstream construction method for tailings management results in an embankment cross section that is more consistent with that of a conventional water retaining dam. A simplified section of a tailings dam using the downstream construction method is shown on Figure 3. This type of embankment requires the greatest volume of construction materials and is therefore the most costly to construct.

Figure 3 illustrates the development of a tailings beach upstream of the downstream embankment section, similar to the tailings beaches presented for the upstream and centerline embankment sections. This assumes that tailings slurry would be discharged from along the embankment crest in all cases, but it should be noted that this is not a fundamental requirement for the staged expansion of the downstream embankment, whereas it is necessary to develop tailings beaches as foundation materials for crest raises constructed by either of the other two methods. Figure 4 illustrates an alternative method of operations wherein the tailings slurry is discharged from a more remote location in the impoundment and the surface pond is contained by the dam raises. In this latter case, the embankment must function as a more conventional water retaining dam, albeit with significant sediment (tailings) accumulation along the bottom of the reservoir.

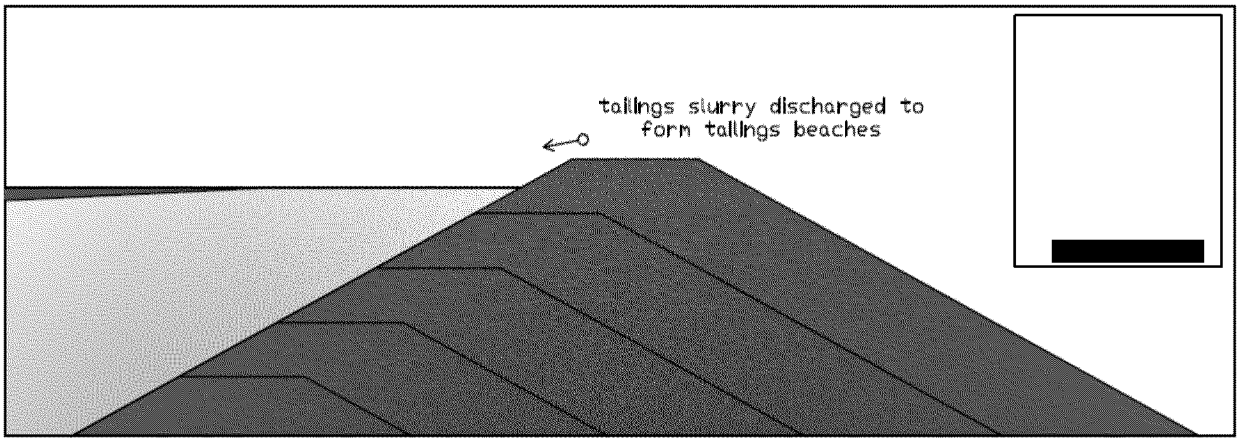

Figure 3 – Downstream Tailings Embankment Construction Method with Adjacent Tailings Beach

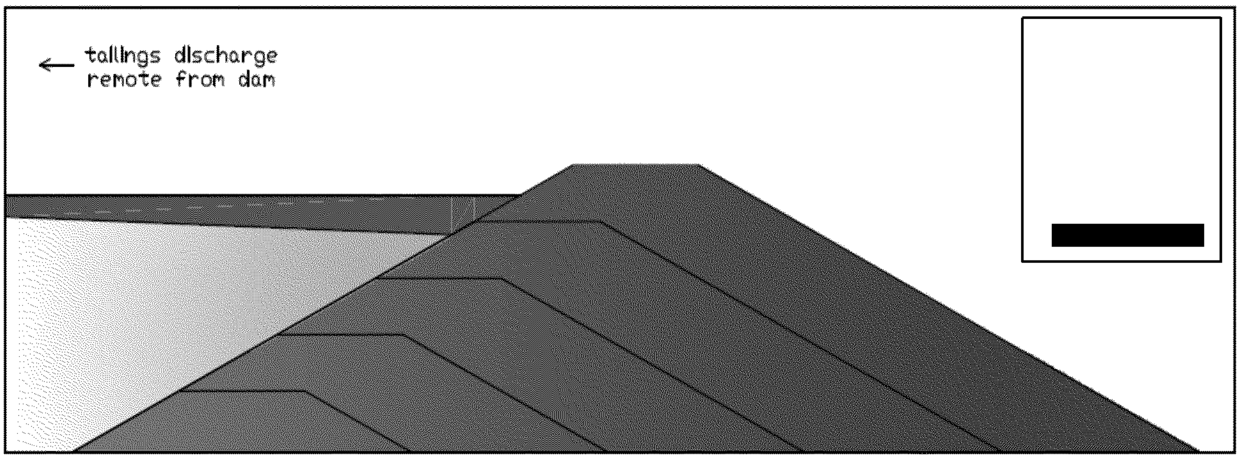

Figure 4 – Downstream Tailings Dam Embankment Construction Method with Remote Tailings Discharge

Either of these two tailings deposition practices can be used successfully with the downstream construction method, but the latter option does not take advantage of the hydraulic conductivity and shear strength properties of the stored tailings solids to enhance stability, improve seepage control, and improve the performance of the structure to the same extent as the former option.

Variations on these basic tailings embankment construction methods have also been implemented. Haile and Brouwer [12] describe the modified centerline construction method that has been successfully implemented in high seismicity areas. Davies *et al.* [13] provide a discussion on an Improved Upstream Construction method that addresses fundamental concerns relating to static or seismically induced liquefaction within the structural zone of the tailings embankment (pp 8).

4.2. Tailings Dam Performance

Most tailings dams are operated satisfactorily and perform in accordance with the design intent. However, there are also some instances where tailings dam failures have occurred. Evaluation of these incidents provides an opportunity to identify the root causes of the incidents and failures so that appropriate measures can be implemented to prevent the recurrence of the problems in the future.

An analysis of 221 dam incidents and failures was carried out by ICOLD as presented in ICOLD Bulletin No. 121.[2] Details of the tailings dam type and cause of incident were reported for 220 of these; 135 of which were failures (Table 3). Incidents due to accidents or groundwater are not included in this total. The ICOLD bulletin states that *'accidents, breaches, and other incidents are often the result of inadequate site investigation, design, construction, operation, or monitoring of the impoundment, or a combination of these'*. [2] These inadequacies would be considered the root cause of the failure, with the failure itself occurring via one, or a number of, failure mechanisms

Table 3. Number and cause of tailings dam failures according to construction method and active / inactive status. [2]

Dam Type	Centerline		Downstream		Unknown		Upstream		Water Retention		Total
Failure Cause	Active	Inactive	Active	Inactive	Active	Inactive	Active	Inactive	Active	Inactive	
Earthquake			1		3		14				18
Erosion					2				1		3
Foundation	1			1	4		3		4		13
Mine Subsidence					2				1		3
Overtopping	1	1	1		6	4	9	2	3	1	28
Seepage			1		1		4		4		10
Slope Instability			1		3		22		3	1	30
Structural			1		5		4		2		12
Unknown					13	3	1		1		18
Total	2	1	5	1	39	7	57	2	19	2	135

The ICOLD data set does not provide information on the year the dam was constructed and the regulation guidelines (if any) in place at the time of construction . The current data set is insufficient to show that there is a trend towards increasing tailings dam failures over time or that high height dams have a greater or lower risk of failure.

The ICOLD data shown in Figure 5 demonstrates that the vast majority of known failures have occurred in tailings dams that have been developed using the upstream construction method. Davies *et al.* [14] also suggest that their tailings dam failure database indicates that *'upstream constructed dams = more incidents'* (pp. 10). In fact, Chilean regulations prohibit the use of the upstream construction method for tailings dams.[10]

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[12] Haile, JP and Brouwer, KJ. 1994. Modified Centerline Construction of Tailings Embankments. Third International Conference on Environmental Issues and Waste Management in Energy and Mineral Production, August 1994. Perth, Australia.

[13] Davies, MP, Lighthall, PC, Rice, S, and Martin, TE. 2002. Design of Tailings Dams and Impoundments, Tailings and Mine Waste Practices SME, Phoenix, 2002.

[14] Davies, MP, Martin, TE, Lighthall, P. 2000. Mine Tailings Dams: When Things Go Wrong. Tailings Dams. Association of State Dam Safety Officials, US Committee on Large Dams, Las Vegas, Nevada. Pp. 261-273.

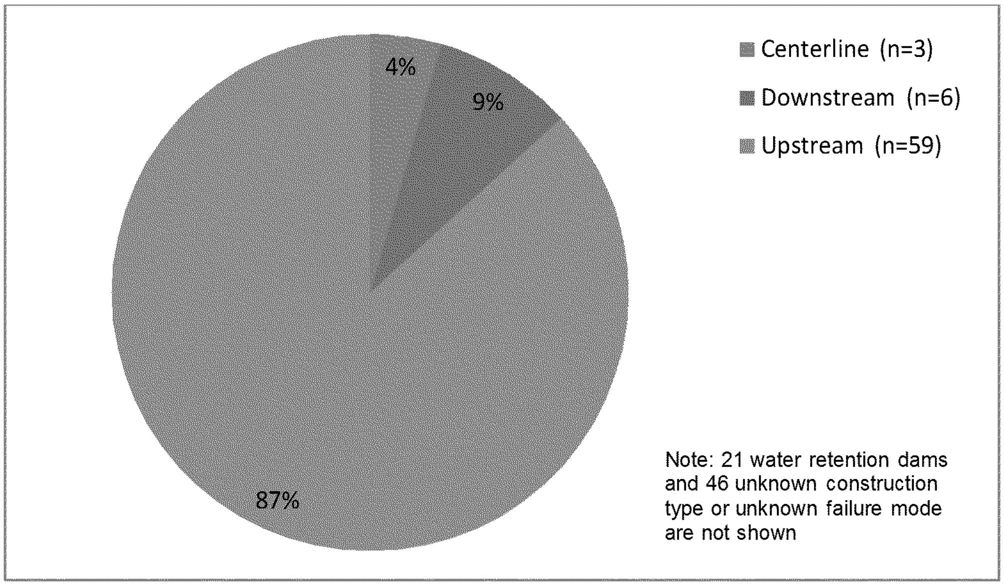

Figure 5 – Total Failures for Upstream, Downstream and Centerline Construction Methods.[2]

The ICOLD data set indicates that there are relatively few instances of catastrophic failure for tailings dams constructed using the centerline and downstream methods as shown in Table 3, as indicated in Figure 5, and as illustrated in Figures 6 and 7 below.

The ICOLD data presented in Figure 7 illustrates that the same failure modes still need to be considered for tailings dams constructed by the downstream or centerline methods, but it is evident these types of tailings dams are inherently more stable. It is noted that there are only three failures reported for tailings dams constructed using the centerline method and seven failures for tailings dams constructed using the downstream method. The statistical significance of this observation is difficult to ascertain due to the relatively few failures that have occurred for either embankment construction technique.

If we assume that the downstream and centerline construction methods are both used in a roughly proportionate number of cases, the data suggests that the centerline construction method has proven to be more dependable, with less chance for design or operator error. The reason for this would likely be related to the requirement that competent tailings beaches need to be developed along the upstream face of the dam in the centerline construction method. The dam raise requires placement of fill materials out onto the beaches and thus operators are motivated to carefully manage the tailings discharge to develop continuous tailings beaches so that the volume of the more expensive fill materials is reduced and so the construction schedule is not adversely impacted. The development of tailings beaches adjacent to the dam is optional for the downstream construction technique, and even when tailings slurry is discharged from along the crest, proper beach development is less important from an operational perspective as it does not influence construction costs or schedule. Thus the downstream tailings embankment may need to routinely function as a water retaining dam, whereas the centerline constructed embankment will typically be isolated from the tailings pond and will therefore function more as a solids retention embankment than a water dam.

One of the most fundamental objectives for compiling and evaluating case histories of dam failures is so that dam designers can learn from past mistakes and thus prevent the occurrence of failures in future. The preface to the ICOLD Bulletin 121[2] includes the following: *"Pierre Londe, President of ICOLD in a lecture ... about lessons from earth dam failures, said that man learned little from success but a lot from his mistakes: learning from our errors is vital for improving our knowledge and promoting safer design."*

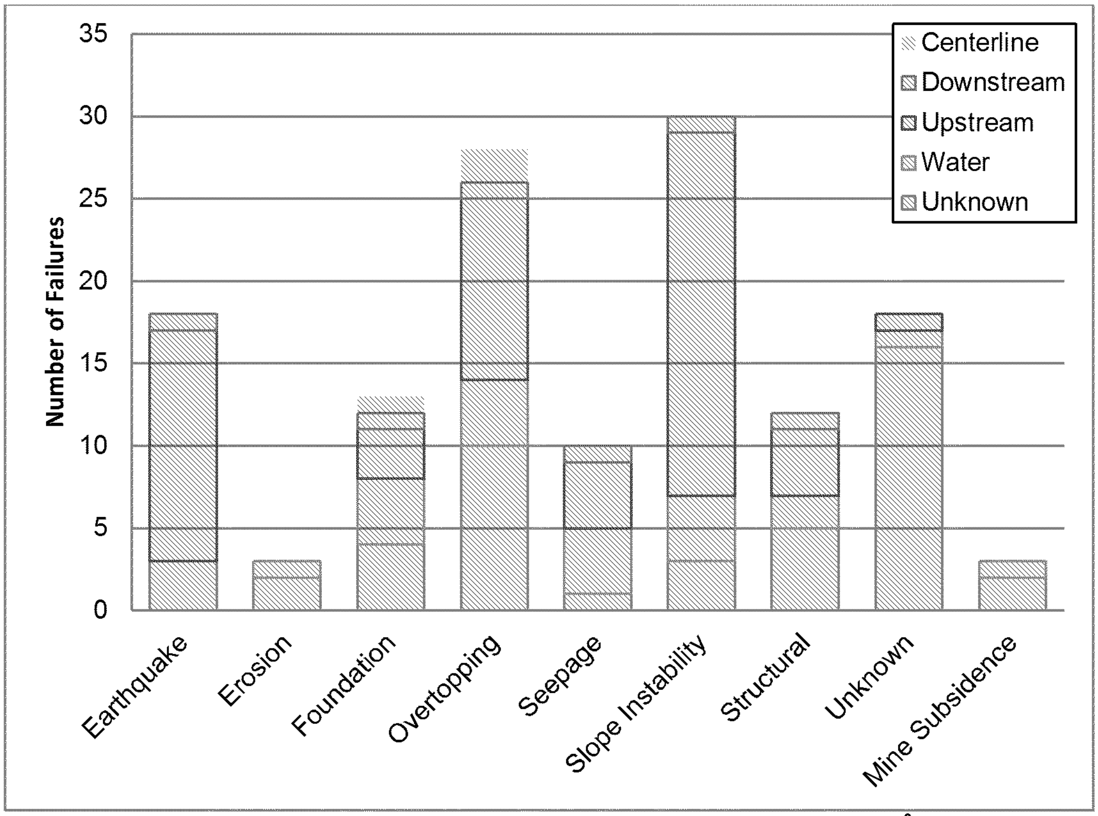

Figure 6 – Original ICOLD Failure Numbers/Modes for all Dams[2]

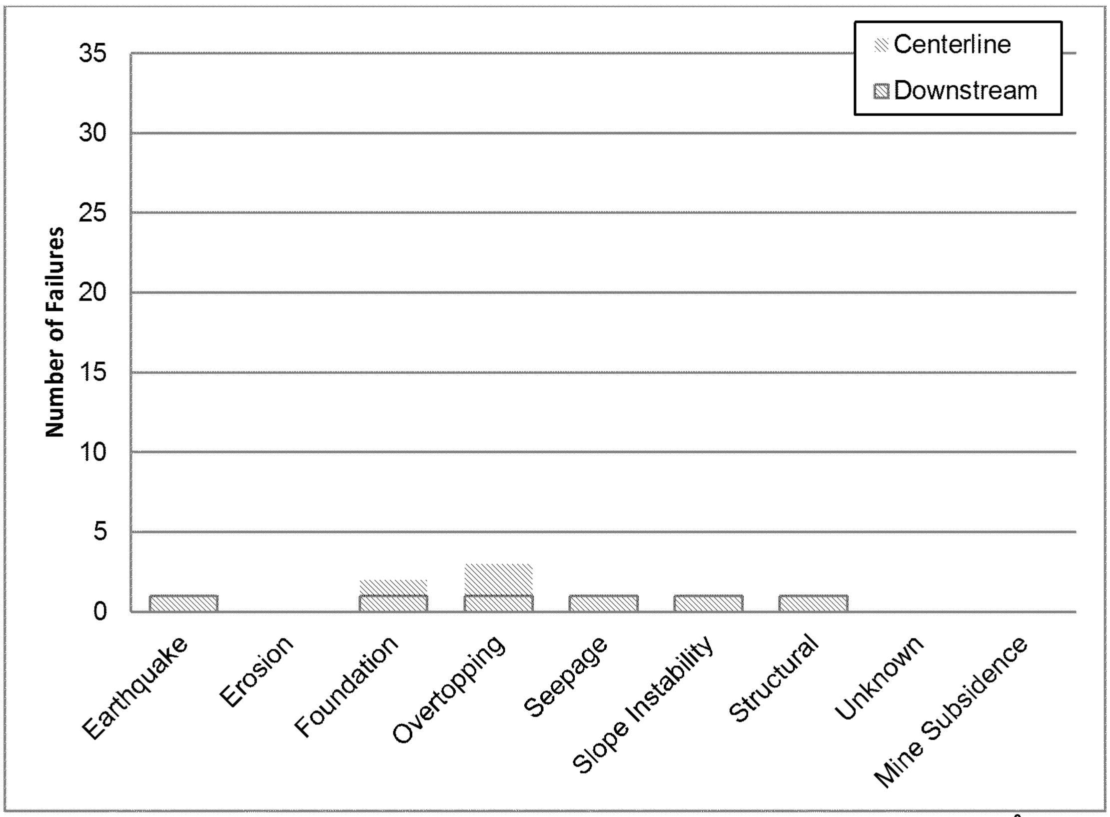

Figure 7 – Failure Numbers/Modes for Downstream and Centerline Tailings Dams[2]

ICOLD Bulletin 121 provides some summary statistics on the frequency of tailings dam failures and states the following; "*In highlighting accidents, the aim is to learn from them, not to condemn.*' (pp 55) Similarly, other authors have studied and expanded the database of tailings dam failures in an effort to prevent future incidents. Davies[14] presents summary statistics of "major" tailings dam incidents and suggests that, based on his tenuous extrapolation to a worldwide inventory of 3500 tailings dams, that "2 to 5 failures per year equates to an annual probability of between 1 in 700 to 1 in 1750" (pp 4). It is imp ortant to note that 3500 worldwide tailings dams is likely an underestimate, as there are 1448 tailings dams in the USA alone.[15] Davies[14] also does not suggest that these statistics represent a probability of failure for any specific tailings dam, but rather indicates that '*there is the potential to essentially eliminate such events with an industry-wide commitment to correct design and stewardship practices*' (pp. 11).

Other authors incorrectly imply that generalized statistics for worldwide tailings dam failures can be applied to individual tailings dams to suggest a high potential for failure over an extended period of time. For example, Chambers and Higman[16] indicate by means of flawed logic that "*the failure rate of tailings dams has remained at roughly one failure every 8 months ....over a 10,000 year lifespan this implies a significant and disproportionate chance of failure for a tailings dam*' (pp4). This premise is erroneous and misleading, as it is incorrect to imply that any particular proposed or actual dam structure is more or less likely to fail based solely on extrapolation of general dam failure statistics. The integrity and stability of any dam structure should rather be ascertained by suitably qualified and competent professionals, whose assessment must take into consideration all relevant aspects of the specific site conditions; the details of the design; as well as the construction, operating and closure parameters that are relevant to the evaluation.

4.3. Design Approaches to Mitigate Risk

As discussed above, the ICOLD data indicates that adopting the centerline or downstream construction technique, rather than the upstream construction method, can provide significant risk mitigation. Even in the event that the tailings along the upstream slope liquefy, the central and downstream portions of the dam remain stable due to their good compaction and drainage characteristics.[12] It is also recognized that the inclusion and management of a tailings beach along the upstream face of the tailings embankment will also provide for significant risk mitigation. However, it is also useful to evaluate all of the potential failure mechanisms in order to illustrate how these incidents can be prevented for existing and future tailings dams.

Analysis of the failure case studies as described in Appendix A has highlighted primary failure mechanism trends. These potential failure modes can be addressed in the initial design process and, by utilizing modern design standards, the risks to stability and safety of the embankment structure can be mitigated. As shown from the analysis of the ICOLD data, the primary failure mechanisms are: slope stability, overtopping, foundation failure, seepage, and erosion (internal and/or external). Extreme events such as earthquakes, floods, and extreme cold are also considered; as well as the risks associated with a lack of adequate technical supervision and/or insufficient quality control measures.

4.3.1. Slope Stability

Slope stability is addressed by the selection of appropriate construction materials and by incorporating suitable internal zoning within the tailings dam to control seepage and the phreatic surface. The design must meet all required factors of safety under static and dynamic (seismic) loading conditions.

4.3.2. Overtopping

Overtopping can occur if the inflow of water exceeds the available storage capacity and freeboard for the facility, or if the storm water routing mechanism is inadequate or blocked. Overtopping of embankments can result in erosion of the downstream fill materials, which can lead to downcutting and embankment instability. The potential for erosive

[15] U.S. National Inventory of Dams. http://geo.usace.army.mil/pgis/f?p=397: 5:0::NO
[16] Chambers, DM and Higman, B. 2011. Long-Term Risks of Tailings Dam Failure. Report by the Center for Science in Public Participation, Bozeman MT. Available: www.csp2.org.

downcutting depends on the nature of the downstream fill materials, as the risk of erosion can be substantially reduced when the downstream fill materials are comprised of coarse rockfill.

Tailings dams are often located high up in a watershed to minimize the upstream catchment area, which reduces the peak flow rate and volume of storm water runoff from the IDF. The critical design consideration is surface pond volume management and the provision of adequate freeboard to address extreme combinations of events. The overall construction, operation and construction schedule will define the minimum embankment crest elevation for each construction season, taking into account seasonal fluctuation in pond volume.

4.3.3. Foundation Stability

Stable foundations and appropriate site investigations are required to properly identify or characterize the foundation materials. The characteristics of the underlying geology must be integrated into the tailings dam design.

4.3.4. Seepage

Incorrect management or inadequate design to control seepage can result in a lack of control over the phreatic surface within the dam structure or foundations, and is a relatively common failure mechanism for the tailings dams investigated in the ICOLD study.

Multiple seepage control mechanisms are normally included within a tailings dam design with the primary objectives being to retain as much water as is reasonably practicable, control the migration pathways through the embankment, and intercept, collect and return any water leaving the system.

The systems available to retain fluids include liners (synthetic geotextiles, clays, or compacted imported fines); dewatering of the tailings to reduce the amount of available water for migration; and, embankment barriers comprising grout/slurry (bentonite) walls positioned vertically within the dam and/or the toe of the upstream slope.

Migration pathways through the embankment, and therefore the phreatic surface within the embankment, can be controlled by various drainage and embankment fill zones within the embankment structure. Examples of drainage measures include vertical drains, horizontal drains, and toe drains.

Another method commonly employed to control the phreatic surface in an embankment is decreasing the hydraulic head at the embankment by maintaining a large beach to keep the surface pond away from the embankment. This is not a requirement for dam stability; however, the embankment design should include seepage and stability assessments assuming water is present along the upstream slope of the dam during extreme water management conditions.

Seepage can be treated and discharged or pumped back into the impoundment. Both options require that seepage collection systems be implemented, and these can include toe drains, wells, trenches, and secondary impoundments further down the hydraulic gradient. Their positioning is controlled by the topography, hydrology, and hydrogeological conditions as well as the physical constraints of the embankment footing.

4.3.5. Erosion

4.3.5.1. Internal Erosion

Internal erosion within an embankment dam is prevented by proper design of adjacent zones and adherence to well established filter relationships. The designs for filters and the filter relationships between adjacent zones are integral components of the embankment and have been the subject of extensive research.

It is important to monitor seepage water clarity and flow rate as indicators for potential internal erosion. Flows with increased sediment content may indicate substantial internal erosion. Also, an increase in seepage flow without a causative influence such as increased rainfall or tailings or impounded water level increases can suggest an increased risk of seepage erosion. Efforts should be made to direct seepage into channels, pipes or secondary containment structures, depending on topographic and environmental considerations, to facilitate monitoring of seepage from all dams.

4.3.5.2. External Erosion

External erosion can be caused by the action of wind or water. The analysis of past failures indicates that slope instability can be caused by erosion of the downstream slope. Alterations in the gradient of the slope can be caused by high rainfall and associated gullying, or the alteration of an existing water channel. Eroded material can also block drains.

Erosion to the downstream slope can be prevented by covering the embankment with coarse material, chemical stabilization, or the use of vegetation. Generally, covering the embankment with coarse material is an economical option, provided a local source is readily available, as is generally the case for mines during operations. Planting of vegetation is the best option for long-term stabilization after closure and often requires the placement of topsoil. The need for on-going irrigation may discount vegetation as a viable solution in certain locations. Toe erosion is rectified by reinforcing the base of the slope with rip rap or the use of other erosion prevention measures.

4.3.6. Extreme Events

4.3.6.1. Earthquakes

The main failure mode for embankment dams under seismic loading is liquefaction of the dam structure (fill materials), the adjacent tailings material, or the underlying foundation soils. Design considerations to prevent liquefaction are a key component of the design process and are discussed in this section, as well as prevention of other failure methods that often relate, in part, to the effects of liquefaction.

Susceptibility to liquefaction can generally be decreased by embankment construction method selection. In general, the downstream construction method using compacted earth and rockfill materials is the most stable under seismic loading. The centerline construction method has similar characteristics but does rely on some support from the tailings beach upstream of the dam centerline for raised sections of the embankment. Liquefaction of the tailings beach as a result of earthquake loading should be assumed in the design process.

Construction of tailings dams by the upstream method should never be considered in seismic zones unless very specific measures are taken to ensure that the tailings forming the structural zone of the embankment are sufficiently dense to prevent liquefaction and the phreatic surface is properly controlled.

Embankment construction material is a primary controlling mechanism in susceptibility to liquefaction in the fill materials. Loose uncompacted sandy tailings or sandy borrow material may be prone to liquefaction when saturated; however, waste rock or borrow material comprising compacted coarse-grained, well graded sand and gravel is unlikely to liquefy.

‘Provided the coarse material comprising the dam is sufficiently well drained and has been sufficiently compacted, shearing strains caused by earthquakes will cause temporary falls in pore pressure (suctions) and so assist in stability in transient forces’.[6]

From his analysis of tailings dam failures, Davies[17] concluded that *‘earthquakes are of little consequence for most non-upstream dams’*. Similarly, Swaisgood[18] conducted extensive studies of earthquake impacts on rockfill embankment structures and from his analysis of 69 case studies taken from 1990 through to 2003, he found that as long as liquefiable layers in the foundation soils were not present, rockfill dams performed in a predictable fashion and remained stable. No rockfill dams were found to have failed due to earthquake loading, and he concluded that:

- The vertical crest settlement experienced due to an earthquake is an index of the amount of deformation and damage incurred by the embankment

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[17] Davies, MP. 2002. Tailings Impoundment Failures: Are Geotechnical Engineers Listening? *Geotechnical News*, pp 31-36.
[18] Swaisgood, JR. 2003. Embankment Dam Deformations caused by Earthquakes, *Pacific Conference on Earthquake Engineering, Paper No. 14.*

- The amount of crest settlement is related primarily to two factors: peak ground acceleration at the dam site and the magnitude of the contributing earthquake
- An approximate estimate of the amount of crest settlement that would occur due to a design earthquake can be made by using mathematical formulae that relate deformations to the peak ground acceleration and earthquake magnitude, and
- Sliding failure along a distinct shear plane is remote.

Jansen[19] states that *'analysis supports the belief held by many that clean coarse, rockfill embankments will not fail as a result of seismic-shaking-caused, deep seated slides, but will only settle and bulge in small, acceptable increments, as each major seismic pulse momentarily causes shear stress to exceed shear strength. The basic conclusion is that if assumed seismic shaking does not cause settlements that exceed available freeboard, the dam will survive acceptably'*.

When designing mitigation methods to ensure dams withstand earthquakes, dam location is important due to the topographical shape of the site and underlying geology. Several features of a tailings dam can be designed to reduce susceptibility to seismic instability including:

- The dam foundation/core contact profile should be gentle and free of sharp and re-entrant edges to preclude the tendency for transverse cracking.
- High capacity internal drainage zones within the embankment should be placed to intercept seepage from transverse cracking associated with seismic activity.
- Filters should be placed on fractured bedrock foundations to preclude piping of the embankment to the foundation.
- The core contact along the upper portions of the abutments should be flared to insure long seepage paths through the abutments.
- Brittle soils should be avoided as impermeable barriers and plastic deformable barriers should be utilized instead.
- A larger freeboard than normal should be constructed to accommodate settlement caused by seismic activity and guard against any potential landslide created seiches (waves caused by landslide).
- A wider dam crest than normal should be specified to accommodate potential cracking. A wider crest produces longer seepage paths should transverse cracks develop.

The final design of a large embankment includes detailed dynamic modeling under the Operating Basis Earthquake and the Maximum Design Earthquake. These analyses are used to confirm the adequacy of the embankment cross-section to account for potential displacements, to confirm the integrity and width of filters, transition zones and drains, and to confirm that predicted embankment crest settlements are within the tolerances allowed for in setting minimum freeboard requirements.

4.3.6.2. Extreme Cold Weather

Unseasonably cold winters can have detrimental effects on tailings dams unless preventative measures have been implemented to deal with extreme or prolonged periods of sub-freezing conditions. Potential risks to the tailings dam structures associated with extreme cold conditions can be divided into difficulties associated with winter construction and difficulties associated with winter operations.

The construction of earthfill and rockfill embankments during extreme winter conditions requires carefully developed procedures, particularly for the installation of geomembranes and other HDPE products, and for placing and compacting fine grained fill materials. The pouring and curing of concrete, and the welding of steel or geomembranes, requires special storage and heating conditions. Careful planning is required to construct the embankments efficiently to ensure that all temperature sensitive activities are scheduled to occur in the summer months, with enough contingency incorporated to ensure that all structures are sufficiently advanced to meet their functional requirements, at least until the subsequent summer construction season.

The operation of tailings dams and overall water management systems can be challenging during extreme cold and freezing conditions, particularly with major pipework installation or relocation. Although manageable, these difficulties

[19] Jansen, RB. 1988. Advanced Dam Engineering for Design, Construction, and Rehabilitation. ISBN 0442243979, *pp 375*.

may be compounded by ice cover on ponds; frozen tailings discharge pipes and beaches, snow cover on structures, and poor visibility. The overall design of the water and waste management facilities should consider these factors and target ease of operation with minimal exterior activity during the winter months.

4.3.6.3. Extreme Floods

The design of the tailings management and water management facilities for extreme flood events has already been discussed in relation to the prevention of overtopping. The provision of sufficient freeboard above the surface pond level is the key to the prevention of overtopping and/or discharging through the emergency spillways.

4.3.7. Adequate Technical Supervision and Quality Control

The management approach taken towards tailings dams will greatly influence the success of a given project. Important considerations are the construction quality control and quality assurance (CQC/QA) measures that are in place to ensure a dam is constructed within the defined design parameters. This can be achieved by a correct contracting approach that clearly defines the roles and responsibilities of the contractors, consultants and supervisors involved in both the facility design and construction management. Clear post-construction operations procedures must also be in place to control the site water management, tailings management, inspections, monitoring, training, emergency action, and performance reporting. These requirements should be clearly outlined in an O&M manual and closure requirements outlined in a detailed closure plan.

The lifecycle of a tailings storage facility is overseen by owners, designers, and regulators. The industry and regulatory community have acknowledged the less than perfect history of tailings impoundments and the industry is committed to adhering to and advancing fundamentally sound design and operating concepts. This is ensured by owners employing competent design consultants with proven track records and employing competent personnel to manage tailing impoundments. Designers now welcome independent reviews throughout the project lifecycle and no longer use generic designs; instead, the emphasis is placed on complete site characterization and unique design solutions. Multiple regulatory bodies are involved and work in partnership to ensure specialist knowledge is applied to the tailings impoundment design, operation, regulation, and review process. Gipson [20] states that; *'Utilizing knowledgeable experienced professionals for policy setting, planning, design, construction and operation of tailing facilities with appropriate internal peer reviews and regulatory oversight by trained and experienced professionals with appropriate levels of funding can lead to the goal of zero failures'.*

5. Construction Precedent for Large Dams

The tailings impoundments for large mining operations are among the largest man-made structures in the world. It is not uncommon for dams to exceed 500 ft in height. The ICOLD records do not include any instances of failure of very large tailings dams. This good performance record is likely a direct result of more attention being paid to the design, operation and regulation of large tailings dams compared to smaller tailings dams, many of which have been built in remote and less developed areas of the world. In particular, there are more thorough design processes, more advanced construction methods and procedures; more careful monitoring; stricter operational controls; and more comprehensive regulatory requirements and reviews. Proposals for the development of large dams tend to attract additional attention and review, and there is a natural tendency for owners, regulators and operators to expect an increased level of design effort as well as greater conservatism in the designs. Figure 8 presents a summary of the largest dams in the world, and provides numerous examples of both water and tailings dams that are greater than 600 ft in height.

Figure 8 illustrates that there is ample precedent for both very high water storage embankment dams and very high tailings dams. Some of the highest tailings dams in the world are located in Chile and Peru, in locations with very high seismic hazard. These dams have experienced large earthquake ground motions and have satisfied design expectations for the seismic loadings experienced.

[20] Gipson, AH. 2003. Tailings Dam Failures – The Human Factor. Proceedings of the Tenth International Conference on Tailings and Mine Waste. Vail, Colorado. October 12 – 15, 2003.

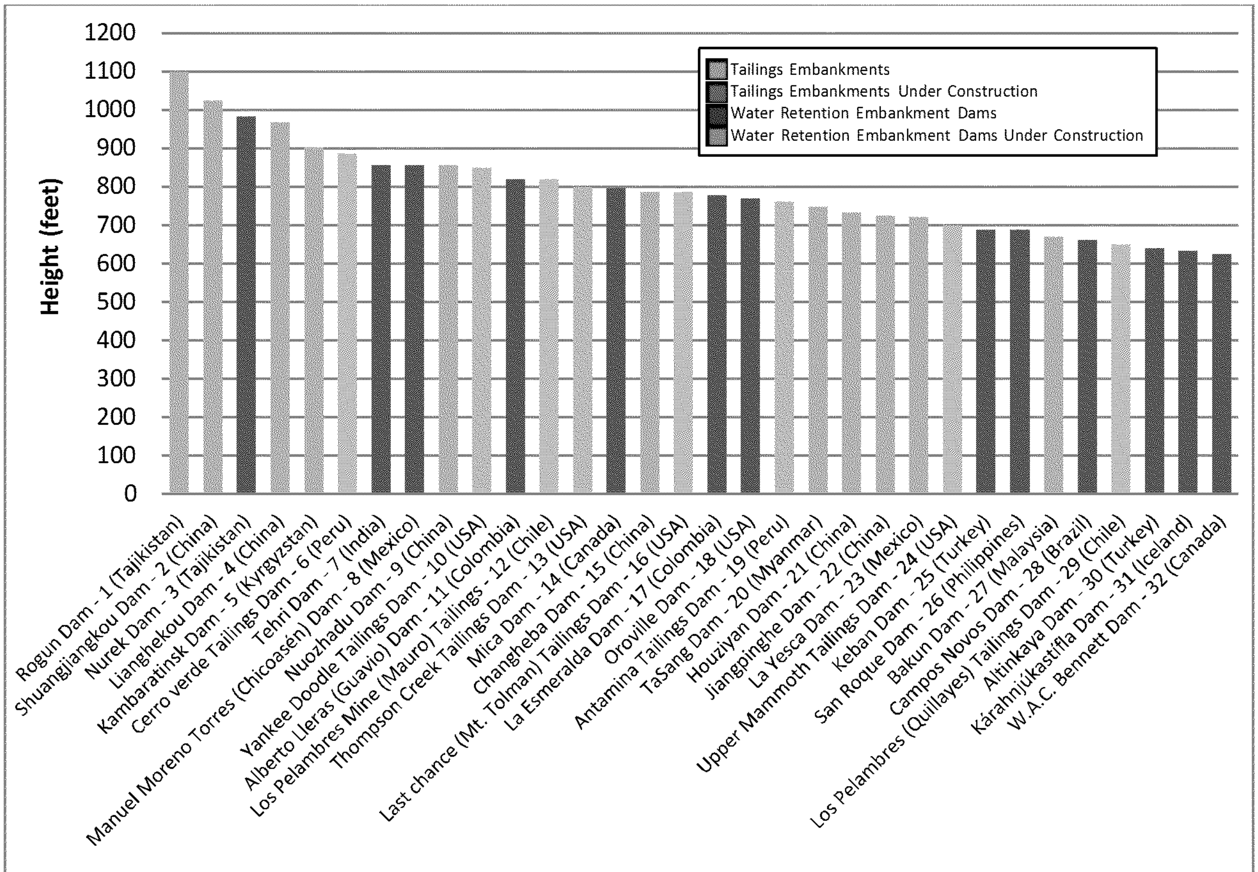

Figure 8 - Tailings and Embankment Dams by Height (ft)[21,22,23,24,25]

6. Site Specific Conditions – The Pebble Project

The Pebble Project is a copper-gold-molybdenum porphyry deposit located in the Bristol Bay Region of southwest Alaska, approximately 17 miles northwest of Iliamna. Site specific circumstances, including earthquakes, hydrological and hydrogeological conditions, and extreme climatic conditions, are discussed in the sub-sections below as they relate to tailings dam design.

6.1. Earthquakes

The Pebble Project area has the potential for large magnitude subduction zone earthquakes, which can occur in the region of southern coastal Alaska. Other potential earthquake sources are also identified through seismotectonic studies that evaluate the geologic and seismologic history of the site. The maximum earthquake potential for each source and frequency of occurrence are identified in these studies. The Maximum Credible Earthquake is determined for each potential earthquake source judged to have an influence on a site. Ground motion parameters, including peak ground acceleration, peak ground velocity, and spectral accelerations, are estimated for each source based on the earthquake source mechanism and magnitude, distance to site, and site geology.

[21] www.wikipedia.org (dam no. 1-5, 7-9, 11, 14, 15, 17, 18, 20-23, 25-28, 30-3). Accessed May 23, 2012.
[22] http://www.eng-tips.com/ (dam no. 6). Accessed May 23, 2012.
[23] Alarcón, JC, Barrera, S, (2003) "Dams of Great Height, a Challenge". Symposium of Tailings, ICOLD, Montreal (dam no. 12, 16, 24, 29)
[24] Thompson Creek Mine Environmental Impact Statement: Mine Expansion, 404 Permit, Land Use Plan Amendment, and Federal Land Disposal. www.blm.gov/id/st/en/info/nepa/nepa/tho mpson_creek_mine.html (dam no. 13)
[25] See also McLeod and Murray (2003)[7] (dam no. 19)

This information is used to analyze the performance of a proposed dam under seismic loading using computer modeling techniques. The modeling provides information on potential deformation and settlement patterns in a dam during and following earthquake loading, which are then used to assess dam performance and to examine the potential for failure mechanisms such as overtopping due to crest settlement, slope instability, and internal erosion.

A number of seismicity studies have been conducted to date for the Pebble Project area including the characterization of the regional seismicity and seismic hazard analyses as required for the design of site facilities. Information has been presented in the Pebble Project Environmental Baseline Document (EBD) 2004 through 2008 (released in 2011).
The EBD provides a summary of the known faults in the Bristol Bay region and indicates that the Lake Clark fault is considered to be inactive. *'The Lake Clark fault has not previously been recognized west of Lake Clark despite numerous attempts by various workers (Detterman and Reed, 1980; Detterman and Reed, 1973; Plafker and others, 1975). Plafker and others (1975) performed aerial and limited field reconnaissance along the entire length of the fault and determined that there is no evidence along the fault trace of offset topographic features or glacial lake deposits suggestive of Quaternary displacement. Given the relatively unvegetated, subdued glacial topography west of Lake Clark, any active fault traces should be easily observed, however, none have been identified to date.' (Koehler, RD, 2010).*

The design of a tailings facility at the Pebble Project area would include consideration of worst case and hypothetical seismic events for the region in which it would be located.

On-going design studies should continue to include examination of all Maximum Credible Earthquake (MCE) scenarios identified for the project site. Possible scenarios being considered include the following:

- Magnitude 9+ Interface Subduction earthquake associated with the Alaska-Aleutian Megathrust
- Magnitude 7.5 Deep Intraslab Subduction earthquake
- Magnitude 7.5 Shallow Crustal earthquake on the Lake Clark Fault, including consideration of hypothetical extensions/splays close to the mine site, and
- Magnitude 6.5 Maximum Background earthquake (assumed to occur directly beneath tailings facilities).

Due to the inherent uncertainty in characterizing the seismic hazard of a region and establishing seismic ground motion parameters (e.g. maximum magnitude and peak ground acceleration predictions for extreme event scenarios), engineering design studies should include evaluation of the robustness of the proposed dam designs. This can be carried out by examining the sensitivity of the dam performance to variations (potential increases) in the seismic design parameters. Such a sensitivity analysis will ensure and demonstrate that these facilities are designed to not only meet required (and regulated) performance objectives, but to exceed them.

6.2. Hydrology and Hydrogeology

The Pebble project is located in a region that experiences significant rainfall and snowfall and has the possibility of large flood events. The area is characterized by a complex inter-related system of surface and groundwater flows which are influenced by geological deposits emplaced during past glaciations of the area.

A detailed understanding of the climate and the surface water and groundwater flow regimes at the Pebble site are essential for quantifying the Inflow Design Flood for the tailings facility and all water management structures, and for the design of the overall site-wide water management system. The overall site-wide water management system must consider site water inputs and outputs. Water inputs will include: direct precipitation and runoff, both onto the mine site and into the impounded area; hydrogeological inputs to both the pit and tailings impoundment; and, runoff from undiverted catchments. Outputs generally include evaporation, sublimation, and controlled discharge of treated effluent, as well as the water permanently stored as pore-water in the tailings.

The importance of these factors has been recognized by the Project proponents, as demonstrated by the extensive climatic, hydrologic and hydrogeologic studies that have been on-going at the Pebble site for several years. The currently on-going surface hydrology program consists of more than 30 stream-flow gauging stations that now have seven years of continuous record as of 2011. This represents an unprecedented hydrologic dataset for a proposed mine development in Alaska, or for that matter, anywhere in the world. Furthermore, groundwater observations have been collected at over 500 locations over the same time period. Both site-wide watershed and groundwater models has been developed using the streamflow and groundwater data for calibration, and these models are capable of predicting hydrologic and hydrogeologic conditions throughout the mine site.[26]

6.3. Extreme Climatic Conditions

The Pebble Project experiences cold weather during the winters. The NOAA weather station at Illiamna Airport, approximately 20 miles from the Pebble Deposit, has recorded average temperatures ranging from -10 °F in December and January to 60 °F in June and July. Temperatures below -45 °F have been recorded in January.

Extreme cold conditions can present difficulties with respect to winter construction and operation of the water and waste management facilities. The construction schedule will need to take this into account. Similarly, winter operations, which may include special design or operation methods to prevent freezing of specific infrastructure, will need to be considered in the design of the facilities so that freezing conditions do not compromise routine operations.

6.4. Considerations for Tailings Dams at Pebble

The Pebble Project represents one of the largest mineral resources in the world. The size of a mine development at the Pebble site would accordingly be very large. The secure management of all tailings produced from the milling operations will be a fundamental requirement for the Project. The following points must be considered in the design of the tailings management system:

- The design process, construction methodology and supervision, plus operational and closure requirements for a tailings storage facility at any mine development project including Pebble must be in accordance with the Alaska Dam Safety Program and other relevant regulations.
- The Pebble Deposit is situated adjacent to an area with significant fisheries resources, and appropriate precautions must be implemented to protect downstream aquatic resources.
- There may be an opportunity to utilize non-mineralized overburden and mine rock obtained from the open pit development as embankment construction materials.
- The upstream construction method must be avoided for the dams.
- Following best practices, tailings should be discharged from along the crest of the tailings dam(s) in order to develop exposed tailings beaches along the face of the embankment(s).
- Regulatory requirements and best practices will ensure that the dam design must account for extreme conditions at the site; including high seismicity, high precipitation, significant storm events, and the cold windy winter climatic conditions. The designs must incorporate adequate provisions to ensure that all potential failure mechanisms are adequately mitigated.
- An understanding of the potential crest settlement following any seismic event is fundamental to establishing the embankment freeboard requirements. Empirical methods (Swaisgood 2003) and numerical modeling methods can be used to ascertain potential embankment deformations due to extreme seismic loading.
- A comprehensive Peer Review process should be implemented, as required by the ADSP.

There is ample precedent for the successful design, construction, and operation of tailings impoundments around the world, including Alaska. Each site is unique and the designs are specific to site conditions. The Fort Knox tailings dam is an example of a large dam that has been constructed and continues to be operated in Alaska. This tailings dam will be raised to its ultimate height of 360 ft in 2013, and it is situated in an area where the cold winter conditions are more severe than those at the Pebble site. The dam is designed to withstand the Probable Maximum Flood as well as the peak ground acceleration of 0.63g generated by a Maximum Credible Earthquake of M7.5. The latest dam *'raise was designed to maintain the necessary high level of stability and integrity as required by Knight Piésold (the engineer), FGMI (the owner), and the Alaska Department of Natural Resources Dam Safety Program (the dam safety regulator), even in the event of a loss of strength due to liquefaction of the tailing.'*[27]

The Pebble Project is expected to be subjected to a high level of scrutiny and has already attracted a significant amount of attention in the media. It is clear that the design, construction, operations and closure of the of the tailings

[26] The Pebble Partnership, 2011. Pebble Project Environmental Baseline Document, 2004 through 2008. Submitted to Environmental Protection Agency, December 17, 2011.
[27] Kerr, TF, Duryea, PD and Quandt, DT. 2011. Tailing Storage at the Fort Knox Mine – An Innovative Expansion to Continue a History of Success. *Proceedings Tailings and Mine Waste 2011.*

dams will be extensively monitored and regulated, consistent with the comprehensive State and Federal requirements for any such development in Alaska. The Pebble Limited Partnership has also reiterated a corporate commitment to meet or exceed all applicable regulatory requirements.

7. Conclusions

Tailings dams can be built to stand indefinitely provided the right procedures, protocols, checks and monitoring are in place throughout all phases of a dam life; including design, construction, operation, closure, and post closure.

An analysis of the failure mechanisms and key risk factors resulting in historical dam failures has highlighted important lessons for the design of new tailings dams. This analysis indicates that most tailings dam failures have occurred in dams constructed using the upstream method. The performance of tailings dams constructed by the centerline or downstream methods has been markedly better, as there are only a relatively few incidences of dam instability for these types of tailings dams. The dam designers must incorporate suitably conservative design provisions to prevent the occurrence of potential failure mechanisms such as embankment overtopping, slope instability, liquefaction due to earthquake shaking, foundation failure, uncontrolled or excessive seepage, structural failure, and erosion.

Appropriate design practices and proper construction methodologies, oversight, and quality control must be implemented during all phases of a tailings storage facility's conception, operation, and closure. This includes prudent, conservative and appropriate designs with independent reviews, and consistent and rigorous construction supervision and operational monitoring, which requires a strong commitment from Owners and Regulatory Authorities. Large embankment dams have a proven performance of successful operations for a variety of extreme events such as very cold weather conditions, extreme floods, and large earthquakes.

Notably, the comprehensive ICOLD records do not include any instances in the world of the failure of a large tailings dam; i.e., over 500 feet in height. Typically these large facilities are subjected to more thorough design processes, more advanced construction methods, more careful monitoring, stricter operational controls, and more comprehensive regulatory requirements and reviews.

Tailings dams for the Pebble Project will be designed and constructed to the highest standards, as required by a strict regulatory process that is already in place through the Alaska Dam Safety Program; by the use of appropriate hazard classification processes to assign appropriately conservative design criteria; and by corporate commitments for meeting or exceeding all regulatory requirements. State-of-the-practice engineering design methods will be applied along with appropriate construction methodologies, coupled with regulated requirements for oversight and quality control. Tailings impoundments for the Pebble project will be designed, constructed and operated to achieve and maintain performance objectives and to form stable long-term landforms in perpetuity. Dam safety inspections, on-going monitoring, and regular reviews will continue well after mine closure to ensure that these objectives are satisfied.

Appendix A

A. Lessons learned - Analysis of past failures, successes and mitigation methods

The International Committee on Large Dams (ICOLD) has complied data on dam failures and incidents. This appendix provides a review of those data and presents illustrative case studies for the common failure mechanisms shown by the data set. Extreme events are also considered and case studies showing successful performance of dam structures during these events are given.

An analysis of 221 dam failures and incidents was carried out by ICOLD and is presented in ICOLD Bulletin No. 121. This bulletin states that *'accidents and other incidents are often the result of inadequate site investigation, design, construction, operation, or monitoring of the impoundment, or a combination of these.'*[2] These inadequacies would be considered the root cause of the failure, with the failure itself occurring via one, or a number of, failure mechanisms. Failure mechanisms include:

- Slope instability
- Overtopping
- Foundation failure
- Seepage, and
- Erosion, both internal and external.
- Mine Subsidence
- Structural failure

Low frequency extreme events, including earthquakes, floods and extreme cold weather, have also contributed to tailings dam failures via the failure mechanisms listed above.

A summary of tailings dam failures, grouped by the principle failure mechanisms, is shown on Figure A1 below. Earthquakes have been included in this summary as the information from ICOLD Bulletin No. 121[2] included earthquakes as a cause of failure without providing the failure mechanism. Tailings dam failures account for 135 of the 221 dam failures and incidents analyzed in ICOLD Bulletin No. 121.[2]

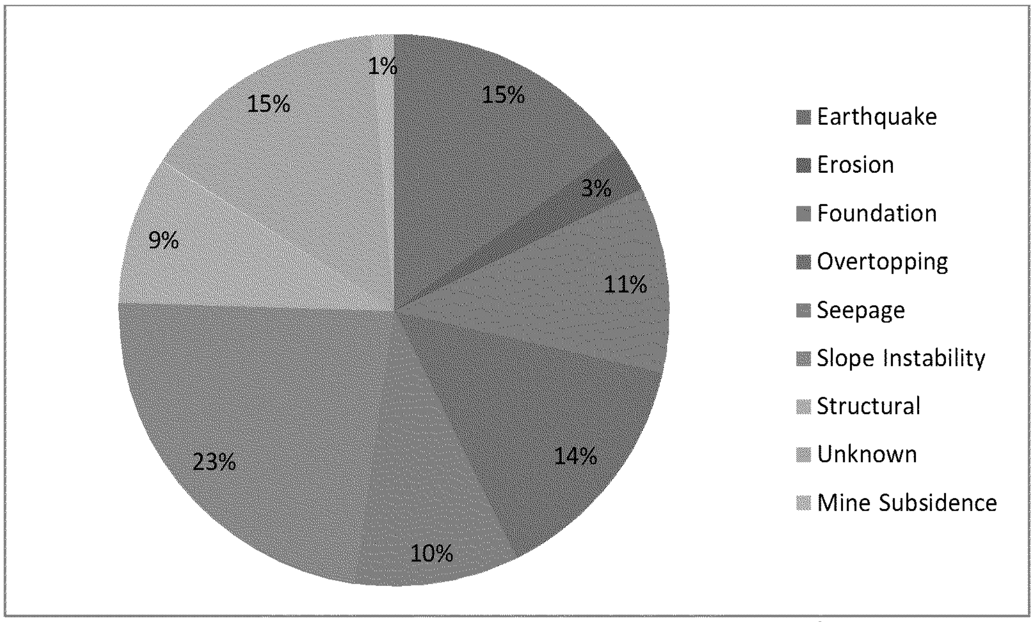

Figure A1 – Failure Mechanisms for Tailings Dams[2]

The importance of an appropriate tailings dam construction method is illustrated on Figure A2, which shows the percentage of breaches associated with upstream, downstream, and centerline layouts. This analysis indicates that the majority of tailings dam failures are predominantly associated with dams constructed using the upstream construction method. Only 9 failures have been recorded for tailings dams that are reported to have been constructed using the centerline or d ownstream methods. Of the three centerline impoundment failures, two were attributed to overtopping and one to foundation failure. The six downstream impoundment failures are attributed to a variety of failure mechanisms including: earthquake, slope instability, overtopping, foundation failure, seepage, and structural. It is also likely that a lack of adequate technical supervision and quality control may have been contributing factors in many of these examples.

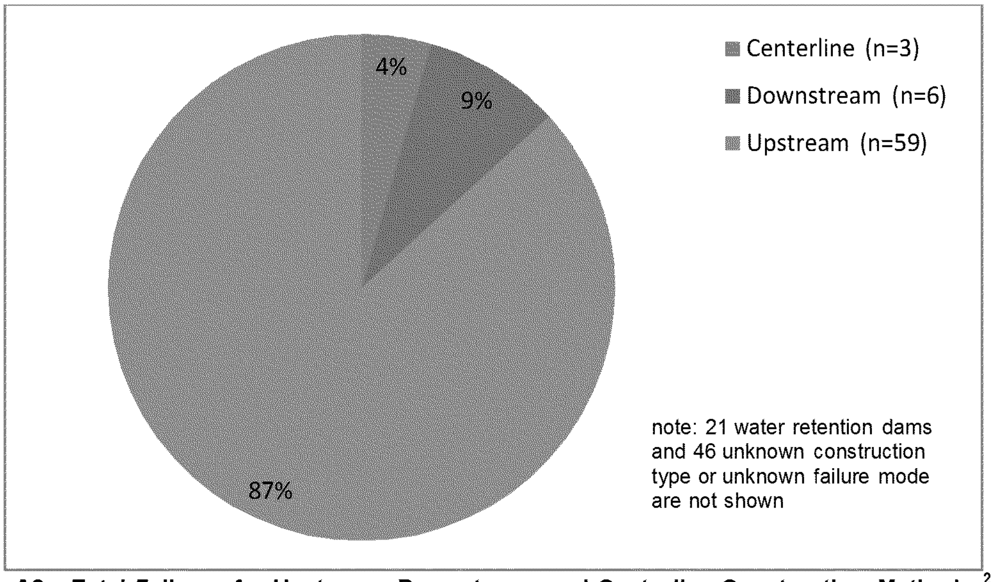

Figure A2 – Total Failures for Upstream, Downstream and Centerline Construction Methods.[2] Total percentages are for calculated for these three dam construction types only.

Thus a key observation from the above is that tailings dams constructed using downstream or centerline methods are much more stable than those constructed using upstream methods. A closer examination of the ICOLD data base illustrates this fact as illustrated in Figures A3 and A4 below.

These figures illustrate that the same failure modes still need to be considered for tailings dams constructed by the downstream or centerline methods, but it is evident that tailings dams constructed using these methods have a significantly better performance record.

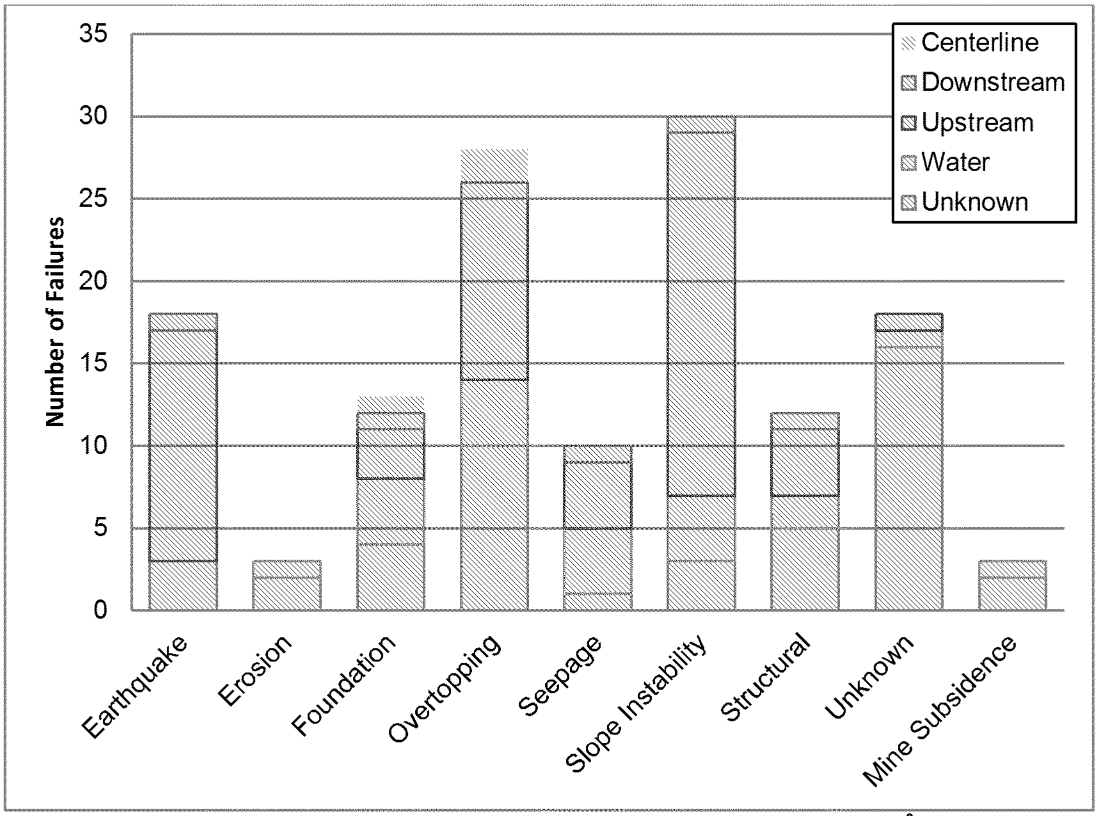

Figure A3 – Original ICOLD Failure Number/Modes for all Dams[2]

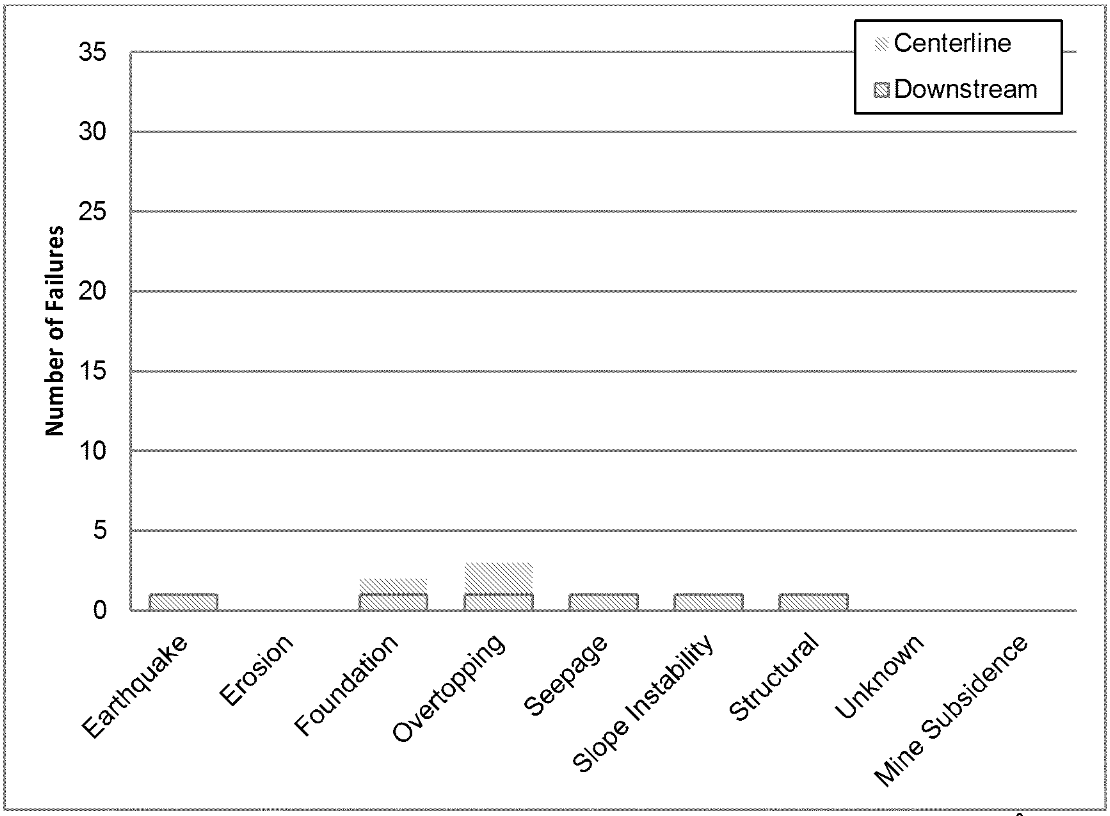

Figure A4 – Failure Number/Modes for Downstream and Centerline Tailings Dams[2]

Table A1. All Centerline and Downstream Tailings Dam Breaches[2]

Name	No.	Active	Location	Dam ht (m)	Tailings type	Dam fill	Cause
Dam type: Centerline							
Dresser No. 4	40	Yes	Washington County, MO, USA	15	Barite	Earth	Foundation: The apparent cause of failure was embankment sliding along residual and alluvial foundation soils. The tailings flowslide reached a nearby drainage and from there entered a creek.
No 1 tailings dam	204	Yes	Middle Arm, Launceston, Tasmania	4	-	Earth	Overtopping: Crest formed of tailings, eroded by wave action. Water containing 95mg/litre released into Tamar river. Cause: retained tailings allowed to rise above crest. Cost of remediation estimated A$ 20,000 - 30,000
Mineral King	188	No	Invermere, British Columbia	6	-	Cycloned Sand Tailings	Overtopping: Dam breach caused by high pond overtopping crest. Diversion ditch blocked by ice during onset of spring snowmelt.
Dam type: Downstream							
Unidentified	168	Yes	Peace River, FL, USA	-	Phosphate	Earth	Seepage: The dam had been raised in height several months prior to the failure using sand fill. At the time of failure, water at least 5 ft deep was in direct contact with the upstream face of the dam, including the interface between the new and old fill. The failure is thought to be related to either the incorporation of logs and brush in the original portion of the structure, or an old decant pipe found at the bottom of the breach. In either case, seepage and piping were the eventual cause of failure. The phosphate clay slimes released produced suspended solids concentrations as high as 8000 ppm in the Peace River.
Silver King	109	Yes	Adams County, ID, USA	9	Copper	Earth	Overtopping: Rain on heavy snowpack caused the impoundment to fill to capacity, and emergency pumping was insufficient to prevent overtopping with the loss of 2 million gallons of water and about 20% of the impounded tailings. Downstream damage consisted of silting of streambeds. The embankment was subsequently repaired and placed back into service.
Portworthy	97	Yes	United Kingdom	15	China clay	Rock	Structural: Dam breach occurred due to structural failure of a decant conduit.
El Cobre New Dam	43	Yes	Chile	19	Copper	Cycloned Sand Tailings	Earthquake: The dam was constructed by cycloning and is inferred to have been raised according to the downstream method with a downstream slope of 3.7:1.0. The impoundment had undergone rapid filling immediately prior to the M7-7 1/4 La Ligua earthquake of March 28, 1965. Eyewitness accounts indicated that the impounded slimes completely liquefied, with waves generated on the surface. Inertial forces combined with increased pressure from the liquefied slimes opened a breach near the abutment, which was rapidly enlarged by the flowslide. The failure, combined with that of the adjacent Old Dam, destroyed the town of El Cobre and killed more than 200 people. Source: Dobry and Alvarez, 1967[28]
Derbyshire	38	No	United Kingdom	8	Coal	-	Foundation: The impoundment had been inactive for 8 years at the time of failure. Foundation materials consisted of 20 ft of clay overlying shale/mudstone bedrock. Failure by foundation sliding was attributed to artesian foundation pore pressures produced by seepage from adjacent active impoundments and natural recharge, with subsidence from underground workings as a contributing cause.
Unidentified	144	Yes	United Kingdom	20	Coal	-	Slope Instability: The failure occurred during regrading operations to stabilize bulging and deformation of the downstream dam slope that had occurred two months previously. Contributing to the failure may have been rise in impoundment fluid levels due to displacement by mine waste being regraded from an adjacent pile. The tailings flow failure covered an area of 4 ha.

[28] Dobry, R. and Alvarez, L. 1967. Seismic Failures of Chilean Tailings Dams. Journal of Soil Mechanics and Foundations Division; Proceedings of the American Society of Civil Engineers, SM6. Vol 5582, p. 237-260.

Table A1 provides a summary of all of the tailings dam failures (breaches) presented in the ICOLD study for embankments constructed using the centerline and downstream construction methods.

The lessons that are learned or that can be re- enforced by examination of dam failures are best illustrated by considering all of the dam failure case histories. Therefore, the following examples have been selected to illustrate the failure mode and are not limited to tailings dams constructed using downstream or centerline methods.

A.1. Slope Instability

Some examples of tailings dam incidents and failures by slope instability are summarized below. Information for the examples was sourced from ICOLD Bulletin 121.[2]

- The Lower Indian Creek Lead Mine tailings dam in the USA suffered damage in 1960. The earthfill tailings dam was originally constructed in 1953 to a height of 45 ft and subsequently raised several times. Slumping occurred on the downstream slope in 1960; the tailings dam was stabilized by the addition of rock fill toe weighting to flatten the overall slope to 1V:3H (18 degrees). The tailings dam achieved a total height of 83 ft in 1976.
- The Maggie Pye China Clay Mine tailings dam in the UK failed in 1970. The tailings dam was 59 ft high and suffered a slope failure immediately following completion of a raise and a period of heavy rainfall. The failure is attributed to high pore-water pressures coupled with an increased load imposed by the raise. Approximately 19,600 yd^3 of tailings were released.
- The Stava Mine tailings dam near Trento, Italy failed on July 19, 1985. The outer embankment of the upper basin gave way and collapsed onto the lower basin, which also collapsed. The sand, slime and water moved downhill at a velocity approaching 55 mph until it reached the river Avisio. The fluid mass caused 286 fatalities and €155 million in property damage. According to subsequent inquiries, the collapse was caused by the chronic instability of the dams, especially the upper dam, which were below the minimum factor of safety required to avoid collapse. In particular, the causes of instability were found to be as follows:
    - Deposited slimes tailings had not consolidated for the following reasons:
        - The foundation soil on which the dams were built was saturated, preventing drainage and settlement of the tailings solids
        - The embankment of the upper basin was not constructed correctly, making drainage very difficult, and
        - The upper basin was built close to the lower one, making drainage more difficult and stability more precarious.
    - The decision to raise the embankment by the upstream construction method, which was the quickest and most inexpensive but also the least stable.
    - The drainage pipes were installed incorrectly.

A.2. Overtopping

Two examples of tailings dam failures due to overtopping and one example of a water retaining embankment dam are summarized below. The water dam has been included herein as the implications of overtopping are expected be similar to those of a tailings dam due to the similar configuration and construction materials. Information for the first two examples, Galena and Baia Mare, was sourced from ICOLD Bulletin 121[2] and information for the final example, Banqiao and Shimantan, was sourced from ICOLD Bulletin 142.[29]

- The Galena Silver Mine tailings dams in the USA failed in 1974. The tailings storage facility was comprised of three tailings dams built in sequence within one valley. A flood event caused by rain falling on snow resulted in a 100 year return period flood. Although the resulting inflow should not have caused the dam to fail, blockage of the diversion channel resulted in a large proportion of the flood waters being directed into the uppermost impoundment. The decant system could not accommodate the inflows and the upper dam failed due to overtopping. This resulted in a cascade failure of the two tailings dams downstream. Five acres of land, including part of a highway and a main railway line, were covered in tailings.
- The Baia Mare tailings dam in Romania failed on January 30, 2000. The failure is attributed to overtopping of the dam by improper water management resulting in insufficient freeboard. The UNEP/OCHA report found that the process of raising the dam could not keep up with the rise in the reservoir water level. The climatic conditions of

[29] International Commission on Large Dams (ICOLD). 2005. Report On the Safe Passage of Extreme Floods. Bulletin Number 142.

the winter season aggravated the situation and led to an uncontrolled rise of the pond level resulting in an overflow of the dam. The spill resulted in the release of 130,800 yd^3 of combined tailings solids and cyanide effluent.

- The Banqiao and Shimantan Reservoir Dams in China were earthfill dams built for flood control and irrigation. The Banqiao, built in 1956, had a crest length of 6627 ft and a maximum height of 80 ft and the Shimantan Dam, built in 1952, had a crest length of 1640 ft and a maximum height of 82 ft. Both dams were overtopped during an extreme rainfall event in 1975. The primary reasons for failure are listed as:
  - The rainstorm was significantly greater than anything experienced in the historical record and as such the short hydrological data set resulted in an under-estimation of the design flood.
  - There was no flood warning system to allow the operators to prepare for the event.
  - Improper reservoir regulation resulted in the water level being higher that the maximum allowable level prior to the event.
  - There was inadequate spillway capacity on both dams.
  - Lack of emergency planning resulting in the Banqiao reservoir spillway gates only being partially opened for the first two days for fear of damage to the downstream basin.

A.3. Foundation Failure

Some examples of tailings dam incidents and failures by foundation failure are summarized below. Information for the first three examples, La Belle Mine, Sipalay Mine, and Willamthorp Mine, is from ICOLD Bulletin 121[2] and information for the final example, Los Frailes, is from the Tailings.info website.[30]

- La Belle Mine in Fayette County, PA, USA slumped in 1985 as a result of a translational slide along an unidentified clay layer dipping downstream. The dam height at the time was 259 ft and slumping occurred along a 787 ft long section. The dam did not fail and was stabilized with the use of rock drains and toe weighting (buttressing).
- The Sipalay Mine in the Philippines failed in 1975 as a result of a slip in the clayey soil foundation. The superficial strata had not been removed prior to construction and the starter dam had not been adequately anchored. The use of mixed mine waste of variable particle sizes was also identified as an issue.
- The Willamthorpe Mine in the UK failed in 1966. The dam was 26 ft high and had been built on gently sloping ground comprising predominantly superficial clay deposits overlying shale/mudstone bedrock. The impoundment had been filled for 8 years prior to its failure, which resulted in a flow of liquefied tailings over a distance of 328 ft. The failure was a result of artesian conditions within the bedrock caused by seepage from impoundments further up the slope and tensile strains induced in the clay as a result of historical underground mine workings.
- The Los Frailes tailings impoundment in Spain failed on April 25, 1998. The impoundment consisted of a rectangular structure approximately 1.2 mi by 0.6 mi, with a maximum height of 89 ft. The failure occurred on the eastern section of the embankment and was attributed to overstressing of the underlying mudstone, and construction induced pore pressures that resulted in a translational failure along a bedding plane in the mudstone. The dam movement liquefied the tailings behind the dam and resulted in the failed dam section undergoing 197 ft of horizontal displacement. An estimated 2.0 million yd^3 of tailings solids and 7.2 million yd^3 of fluid effluent were lost, flowing into the Agrio and Guadiamar Rivers, and covering 13.5 mi^2 of agricultural land. The resulting cleanup required the removal of 5.2 to 6.5 million yd^3 of solids from the surrounding area.

A.4. Seepage

Examples of tailings dam failures by uncontrolled seepage are summarized below. The information for the first two examples, Zletovo and Merriespruit, was sourced from ICOLD Bulletin 121[2] and information for the final example, Magyar, was sourced from InfoMine.[31]

- The Zletovo Lead Mine in Yugoslavia failed in March 1976. The dam was a 49 ft high tailings impoundment and failed as a result of the phreatic surface emerging from the steep downstream slope of the embankment. Prior to the failure, there was evidence of seepage issuing from the slope above the failure point. The resulting tailings flow contaminated the nearby river and resulted in the water supply to the local town being disconnected for 24 hours.

[30] Morin, K. and Hutt, N. 1999. Tailings.info – Los Frailes, Aznalcollar, Spain. www.tailings.info/losfrailes.htm .
[31] Zanbak, C. 2010. Failure Mechanisms and Kinetics of Ajka Tailings Pond Incident, 4 Oct.2010 [on-line]. www.informine.com/publcations/docs/Zanbak 2010.pdf

- The Merriespruit Gold Mine tailings dam in South Africa failed on February 22, 1994. The tailings dam was 102 ft high and had been constructed upslope of the town of Merriespruit. The impoundment had been previously closed but had continued to be used for the occasional disposal of waste water along with a small fraction of tailings. This resulted in the migration of the surface pond towards the edge of the impoundment and the reduction of freeboard. Continued migration of the surface pond towards the edge of the impoundment eventually cut the pond off from the decant system and a subsequent heavy rainfall caused an increase in the pond elevation, along with excessive seepage, which led to a dam breach. Seventeen people died due to inundation from the failure.
- The Magyar Aluminum ZRt tailings dam in Ajka, Hungary failed on October 4, 2010. Approximately 916,000 ft^3 of effluent and tailings slurry was released as a result of the breach, representing 10% of the total solids contained by the dam. The failure was attributed primarily to a seepage induced shear failure, which likely initiated static liquefaction of the tailings. The failure originated 984 ft east of the breach location where seepage through the dam structure increased pore pressures and resulted in the instability. This resulted in the separation of the northwest intersection of the dam as the northern section of the dam slid east towards the original point of failure. The failure was also attributed to inadequate maintenance and monitoring because the seepage and resulting erosion of the crest were evident in photographs taken of the dam in June of the same year, as well as to structural design weaknesses inherent in the angle of the dam at the failed section.

A.5. Erosion

Examples of tailings dam incidents and failures caused by internal erosion are summarized below. Information for the first two examples, Cyprus Thompson Creek and Blackbird Sweeney, was sourced from ICOLD Bulletin 121,[2] and information for Omai is from Geotechnical News.[32]

- The Cyprus Thompson Creek tailings dam in the USA had an incident in 1989. An 8.2 ft diameter by 4.9 ft deep sinkhole appeared in the downstream slope. The sinkhole was attributed to internal erosion or piping into an embankment base drain constructed using a 6 inch diameter PVC pipe wrapped in a filter cloth. It is assumed that the filter fabric was inadequate and resulted in fine tailings discharging into the PVC pipe.
- The Blackbird Sweeney tailings dam in the USA failed in 1980. The dam was breached due to piping around the decant outlet system.
- The Omai Gold Mine tailings dam in Guyana failed on August 19, 1995. The dam had been in operation for 3 years and had been continuously raised by the mine to a height of nearly 150 ft. The dam had an upstream sloping core overlying a sand filter and downstream rockfill section. The failure mechanism was determined to be internal erosion resulting from the lack of a transition zone or proper filter relationship between the sand filter and underlying rockfill, which was exacerbated by blockage of the outlet drains. This resulted in migration of the sand filter and overlying core material into the rockfill and the development of sink holes in the upstream face through which a large volume of water and tailings were released.

An example of damage to a dam as a result of erosion to the external surface is summarized below.

- A lead and zinc tailings dam at Mojkovac, Montenegro, suffered damage due to toe erosion in 1992. The embankment was 66 ft high and covered with a geomembrane on the upstream side to prevent migration of tailings water into the local watercourse. The river level was raised by 10 ft during a flood event and the elevated flow caused 7 ft of horizontal erosion along the dam toe. A geomembrane liner prevented the flow of the tailings water into the downstream tailings slope and the dam held. Remediation included reloading the toe of the slope with replacement fill and diverting the course of the river away from the dam.[2]

A.6. Extreme Events

A.6.i. Earthquakes

Examples of dam slope instability due to earthquakes are summarized below. The information is sourced from ICOLD Bulletin 121.[2]

- The Bellavista tailings dam in Chile failed in 1965. The tailings dam was built by the upstream method to a height of 66 ft with an outside slope of 1V:1.4H (36 degrees). It failed during the La Liqua earthquake, which

[32] Haile, JP. 1997. Discussion of the Failure of the Omai Tailings Dam. *Geotechnical News, March 1997. Geospec, pp 44-49.*

had a magnitude of 7.7. At the time the tailings beach was only 26 ft wide, which contributed to the failure of the dam.

- The Hokkaido tailings dam in Japan failed in 1968. The tailings dam was extended onto liquefiable sandy tailings beaches and reached a height of 39 ft with an outside slope of 1V:3H (18 degrees). It failed during the Tokachi-Oki earthquake, which had a magnitude of 7.8; 118,000 yd^3 of tailings flowed from the breach and temporarily blocked a river.
- The Mochikoshi Gold Mine tailings dams in Japan failed in 1978. Two dams failed as a result of the liquefaction of tailings behind the dam structures caused by the Izu-Ohshim-Kinkai earthquakes, which had a magnitude of 7 with an aftershock of 5.8. Peak ground acceleration at the site was approximately 0.15 to 0.25 g. The first dam failed during the shock event, the second failed 24 hours later. Both dams were constructed by the upstream method.

Note that the three examples of tailings dam failure from a seismic event above were constructed by the upstream construction method. 'Seed[33] *said that it was noteworthy that no failures have been reported in dams built of clayey soils even under the strongest earthquake shaking conditions imaginable, and that all cases of slope failure reported have involved sandy soil.'*.[2] It should be noted that '*older embankments built of inadequately compacted sand or silt, and older design tailings dams, represent nearly all the known cases of failures, primarily as a result of the liquefaction of those materials'*.[34]

An example of earthquake induced failure of a downstream dam is the El Cobre tailings dam as indicated in Table A1:

- The ICOLD summary states; '*The dam was constructed by cycloning and is inferred to have been raised according to the downstream method*'. It is noted that the construction method was '*inferred*' and implies that detailed design and as-built construction drawings were unavailable. The design, construction and quality assurance/quality control protocols were probably absent or at the least inadequate. Dobry and Alvarez (1967)[28] indicate that cyclone sand materials were hydraulically placed - likely in a loose, uncompacted manner. This is a dangerous practice in a highly seismic area, as loose, uncompacted saturated tailings sand is highly susceptible to liquefaction and strength loss during seismic shaking. It is noted that the '*impoundment had undergone rapid filling immediately prior to the M7-7 1/4 La Ligua earthquake*' which suggests saturation of the loose embankment cyclone sandfill and that '*eyewitness accounts indicated that the impounded slimes completely liquefied'*. Although a large earthquake is listed as the cause of failure, it is evident that the improper design, as well as inappropriate construction (lack of compaction), poor operating practices and lack of appropriate monitoring were also possible contributing factors.

Some examples of successful performance of tailings dams during seismic events are summarized below. The information was also sourced from ICOLD Bulletin 121.[2]

- The Tokiwa tailings dam in Kobe, Japan was hit by a magnitude 6.9 earthquake on January 17, 1995 (the HyogoKen Nanbu Earthquake). The tailings dam is a zoned earth fill dam with a height of 108 ft. The earthquake epicenter was located 12 mi southwest of the city of Kobe, approximately 6 mi from the Tokiwa dam. The dam experienced moderate cracking in the crest pavement near both abutments. Although one of these cracks extended to the core, the main structure of the dam remained intact as the crack was confined to the freeboard zone.
- The Northridge Earthquake in California occurred on January 17, 1994 and had a magnitude of 6.7. 105 dams were located within a 47 mi radius of the epicenter. Of these 11 earthfill and rockfill dams experienced some cracking and slope movement; '*...none of these presented an immediate threat to life or property. This satisfactory performance may result, to a significant extent, from the fact that, in California, most significant dams have been re-evaluated for the Maximum Credible Earthquake (MCE).*'[34]
- The Antofagasta Earthquake in Chile occurred on November 14, 2007 and had a magnitude of 7.7. A subsequent aftershock has a magnitude of 5.7. Multiple mines, and their associated tailings dams, were operational within the region including BHP Billiton's Escondida Mine, the Cerro Colorado copper mine, Freeport-McMoRan's operations at the Candelaria and El Abra mines, and Codelco's Coldeco Norte mine. The

[33] Seed, HB. 1979. Consideration in the earthquake-resistant design of earth and rockfill dams. *19th Rankine Lecture. Geotechnique vol 29, no 3, pp 215-263.*
[34] International Commission on Large Dams (ICOLD) and the United Nations Environmental Programme (UNEP). 2001a. Design Features of Dam to Resist Ground Motion. Bulletin Number 120.

aforementioned mines had associated tailings storage facilities, which were not adversely affected by the earthquake.

Additional information regarding the seismic performance of tailings dams may be obtained from case studies of the seismic performance of embankment dams. ICOLD [1] has indicated that *'tailings dams constructed by downstream and centerline methods share many characteristics with embankment dams. Thus, information on the seismic performance of embankment dams provides an additional valuable database.'*

One example is the 154 ft high Los Angeles Dam (LAD) built in 1979. *'The dam comprises upstream and downstream shells of compacted silty sand, a central vertical chimney drain, a downstream near horizontal drainage blanket, and a silty clay core upstream from the chimney drain.'* [34] The downstream slope is at a slope of 1V:3H. The Northridge Earthquake epicenter was located approximately 6 miles southwest of the embankment dam at a depth of 12 miles. The earthquake produced some of the largest peak ground accelerations ever recorded, in the range of 0.5 to 1.0 g, and the embankment dam experienced a peak ground acceleration of 0.42 g. Higher values were recorded in areas of alluvium that were affected by seismic amplification. *'The embankment experienced a maximum crest settlement of 9 cm and approximately 2.5 cm of horizontal non recoverable crest displacement. The downstream slope settled up to 2 cm, and moved laterally slightly in excess of 5 cm downstream'*. [34]

The LAD is a useful case study because of the quantity and quality of seismic data and profiling of the settlement after the event. It is important in terms of design because *'observed performance of LAD during the Northridge Earthquake was found to reasonably match the settlement and acceleration histories subsequently calculated through nonlinear analysis procedures, thereby providing another verification of the validity of modern dam evaluation procedures'*. [34]

A.6.ii. Extreme Cold Weather

Cold winters may have detrimental effects on tailings dams when preventative measures have not been implemented to deal with extreme or prolonged periods of sub-freezing conditions. Potential failure mechanisms include:

- Overtopping, when there is insufficient freeboard to cope with snow melt or freezing of hydraulic systems, including decants, spillway gates, embankment drains, and
- Slope instability, when ice lenses form in the downstream slope.

An example of failure initiated by cold conditions is the Iron Dyke tailings dam in Kimberley, British Columbia, which failed in 1948. The principal cause is thought to be the occurrence of high runoff while the downstream slope was frozen, resulting in the phreatic surface being raised.

A.6.iii. Extreme Floods

The Dahuofang Dam in Liaoning Province, China is an earthfill dam constructed in 1958. The dam underwent several improvements following failure of the Banqiao and Shimantan Reservoir Dams in 1975 (see Section A.2). The first improvement was carried out in 1975, with raising of the radial spillway gates and increasing the freeboard during normal operations. The second improvement was carried out between 1976 and 1978, when the dam height was increased by 1.8 ft and a second emergency spillway was constructed. Also, in 1995 a hydrological monitoring system comprising 14 remote rainfall gauges was installed in the catchment area. The goal of these improvements was to comply with the 1 in 10,000 year PMF design regulation implemented following failure of the Banqiao and Shimantan Reservoir Dams.

The Dahuofang reservoir basin experienced an average of 12.8 inches of precipitation over a period of 52 hours in July of 2005. This event had an estimated return period of 1000 years based on the flow rate entering the reservoir. Operators had approximately 9 hours warning of the impending flood event and the spillway gates were opened in advance. Detailed rainfall data allowed the prediction of the peak water level within the reservoir; the predictability of the flow rates allowed the reservoir to act as a buffer and control discharge with an estimated reduction of 50% in the peak flow rate to the downstream watercourse. The emergency spillway was not required. The main spillway sustained minor damage from erosion of the concrete believed to be due to irregularities on the surface of the spillway and possible damage caused by repetitive freezing. [29]

A.7. Lack of Adequate Technical Supervision and Quality Control

Some examples of a lack of adequate technical supervision and quality control from the incidents summarized above include:

- The Zletovo Lead Mine in Yugoslavia and the Magyar Aluminum ZRt tailings dam in Ajka, Hungary where seepage was evident on the downstream slope prior to failure.
- The Merriespruit Gold Mine tailings dam in South Africa where the tailings and pond water were incorrectly managed and the surface pond was cut off from its own decant system.
- The Omai Gold Mine tailings dam in Guyana where construction of raises failed to comply with basic design principles and a lack of proper technical supervision allowed obvious deficiencies to go unnoticed.

A.8. Discussion

The above categories of failure can occur as a result of multiple contributing factors and can be grouped into the following broad categories:

- Failures due to the inappropriate selection of site specific design inputs
- Failures due to inadequate design, and
- Failures due to a lack of control over construction and operations, including site-wide water management.

Site specific design inputs cover design considerations unique to the proposed location. These inputs include derivation of the appropriate design earthquake and inflow design flood, and consideration of extreme climatic variations. The selection of the design earthquake and inflow design flood events are based on the dam hazard classification .

Design issues relevant to every site include proper definition of the geological and geotechnical foundation conditions, identification and characterization of construction materials, selection of an appropriate tailings dam layout and construction technique, detailed design of all geotechnical structures, seepage and stability modeling under normal and extreme conditions, tailings deposition and water management plans, and designing for closure. A key design issue is proper definition of the overall site-wide water management plan and modeling of the plan under extreme conditions. The construction and operation management approach to tailings dams will also influence the success of a given project.

Author Biographies

Jeremy Haile, P.E., obtained a M.Sc. degree (with Distinction) in Soil Science from the University of London, and an M.A. in Engineering Sciences and Economics from Oxford University, where he was a Rhodes Scholar. He is the President of Knight Piésold Ltd and has over 40 years of experience on more than 35 water dam and tailings dam projects around the world. He is a Professional Engineer in numerous jurisdictions in Canada and the USA, including Alaska. Jeremy was a Senior Reviewer and/or Engineer of Record for the tailings dams at both the Fort Knox and Kensington Mines in Alaska.

Ken Brouwer, P.E., obtained a Bachelor of Applied Science degree in Geological Engineering (1982) and a Master's degree in Civil Engineering (1985) from the University of British Columbia. He is the Managing Director of the Knight Piésold Vancouver office and has 30 years of experience on numerous water dams and tailings management projects situated throughout North America, as well as at diverse locales around the world. He is a registered Professional Engineer in Alaska, Washington, Montana, British Columbia and Northwest Territories/Nunavut. Ken has been a Senior Reviewer for the design and development of various projects in Alaska including the Fort Knox and Kensington mines, as well as for design studies on the Pebble Project.

Attachment 2
Development of Stable Waste Rock Piles in Alaska

White Paper No. 2
Topic: Waste Rock Piles
Title: Development of Stable Waste Rock Piles in Alaska
Author: Les J. Galbraith, P.Eng.

Abstract

Waste rock piles are developed to store non-economic rock and overburden materials for open pit mining operations. Waste rock piles are potentially large structures that are progressively constructed during mine operations in accordance with relevant Alaska regulations, legislation, and guidelines. Well established investigation methods, design procedures, operating requirements, and monitoring practices have been developed on the basis of experience at other large mining operations in North America. Some of the key considerations for the development of stable waste rock piles at Alaska mines are summarized, along with requirements for establishing stable permanent reclaimed landforms after mine closure. Some site specific considerations to ensure stable waste rock piles at the proposed Pebble Project development are also discussed.

1. Introduction

Mine waste rock piles are typically constructed from rock and overburden materials that have been excavated to access ore grade materials during mining operations. Waste rock piles can be large structures, and for some open pit mines are among the largest man-made structures in the world. Waste piles can evolve to become new landforms when reclaimed after closure of a mining operation. The ultimate size of the piles is dictated by a variety of site specific and operational factors, but EPA notes that; '*Where competent foundation materials are found and adequate drainage is provided, the height of the pile is generally unlimited'*.[2]

The design and construction requirements for waste rock piles include the development and evaluation of a hazard rating for the waste pile. This in turn defines the level of detail required to support the design, which includes consideration of the geotechnical and hydrogeological conditions, waste rock material parameters, placement methods, site meteorological conditions, seismic conditions, and the closure and reclamation requirements.

This paper presents an overview of the design, construction, and operation methods for the development of stable waste rock piles, with a discussion of cold region considerations and specific considerations for the Pebble Project. It is also very important to characterize the waste and segregate the materials based on detailed geochemical characterizations so that the waste piles can be designed and managed to mitigate environmental impacts and to prevent adverse water quality impacts to down gradient surface water and groundwater. However, this paper focuses on the physical aspects of waste rock piles; the geochemical considerations are beyond the scope of this paper.

2. Design and Construction Practices for Stable Waste Rock Piles

Open pit mining operations incorporate waste rock piles for the disposal of overburden and non-mineralized or uneconomic rock removed to facilitate recovery of the mineralized ore materials. The storage requirement for the waste rock piles is directly related to the size of the ore deposit. Mining engineers refer to the stripping ratio, which provides an indication of the tons of waste material removed to allow recovery of a ton of ore. Stripping ratios are often in excess of 1 to 1 (i.e. 1 ton of waste is removed for every ton of ore processed) for large open pit operations.

Maintaining a short waste haulage distance is a fundamental economic consideration; waste rock piles are situated as close to the ore recovery activities as possible. Keeping the waste rock piles close to the mine also serves to reduce the mine footprint area, facilitate water management, and minimize environmental impacts associated with the mine development.

There are thousands of mines around the world and each mine can have multiple waste rock piles resulting in multiple thousands of waste rock piles worldwide. These waste rock piles have frequently been developed in remote areas, often with little to no design or operational controls. Most of these piles perform satisfactorily, but there have also been instances where significant waste rock pile failures have occurred. The inherent physical stability of waste rock piles should never be assumed. Current regulations and expectations for modern, responsible mine development require that waste rock piles be investigated, designed, managed and reclaimed appropriately to ensure long term stability.

3. Regulations for Alaska

The disposal of waste rock in Alaska is regulated by the Alaska Department of Natural Resources (DNR) under Alaska Statute 27.19. The regulations address stability, acid rock drainage, and long term reclamation requirements. The regulatory environment in the state of Alaska for waste rock management from mining operations relates to the unique conditions that occur in parts of the state, including a fragile environment, high seismicity, high precipitation, and permafrost conditions. The special waste management practices necessitated by these conditions were previously examined by the US Environmental Protection Agency's (EPA) in a program to regulate mining waste, as presented in the May, 1990 "Strawman II" document.[1] The Design and Operation of Waste Rock Piles at Noncoal Mines, also published by the EPA in July 1995,[2] represents a summary of the Strawman II objectives in addition to previous work undertaken by the Resource Conservation and Recovery Act (RCRA).

Although much of the regulations relate to the control of leachable waste water from the waste rock pile, the EPA and RCRA also provide guidelines for:

- Waste rock pile configuration options
- Preliminary design considerations, such as waste rock characterization and site characterization
- Stability factors, such as foundation stability and waste rock pile stability
- Construction and operation methodologies
- Monitoring methods, and
- Closure and reclamation requirements.

A discussion of the process is presented in the subsequent sections.

4. Waste Rock Pile Configuration Options

There are several different configuration options for mine waste rock piles. The five basic types based on geometric shape are illustrated on Figure 1 below as defined by Taylor and Greenwood.[3] However, in practical terms, a waste rock pile may be a combination of several of the configurations depicted in Figure 1.

Valley Fills can either partially or completely fill the valley in which they are found. If a Valley Fill only partially fills the valley, culverts, flow-through rock drains, or diversions can be constructed to control surface and groundwater flows within the catchment. If a Valley Fill completely fills the valley, it can also be referred to as a "Head-of-Hollow" fill. The surface of the waste rock pile is generally graded or sloped in order to prevent water impoundment at the head of the valley.

Cross-Valley Fills are a variation of Valley Fills where the embankment extends from one side of the valley to the other while crossing over the drainage. The upstream portion of the valley is not completely filled and fill slopes can be constructed to span in both the upstream and downstream directions. Water is generally conveyed around or through the fill via culverts, flow-through rock drains, or diversions, to prevent water impoundment behind the waste pile.

Side-Hill Fills do not block any major drainage courses as they are constructed on sloping terrain. Side-Hill Fills with fill slopes formed on both sides of the ridge line or crest are referred to as a Ridge Crest Fill.

[1] U.S. Environmental Protection Agency (EPA) (1990), "Strawman II, Recommendations for a Regulatory Program for Mining Waste and Materials Under Subtitle D of the Resource Conservation and Recovery Act." Office of Solid Waste.
[2] U.S. Environmental Protection Agency (EPA) (1995), "The Design and Operation of Waste Rock Piles and Noncoal Mines". Office of Solid Waste.
[3] Taylor, MJ and Greenwood, RJ. 1985, Classification and Surface Water Controls. In: Design of Non-Impounding Mine Waste Dumps. MK McCarter, editor. Society of Mining Engineers of the American Institute of Mining, Metallurgical and Petroleum Engineers, Inc.

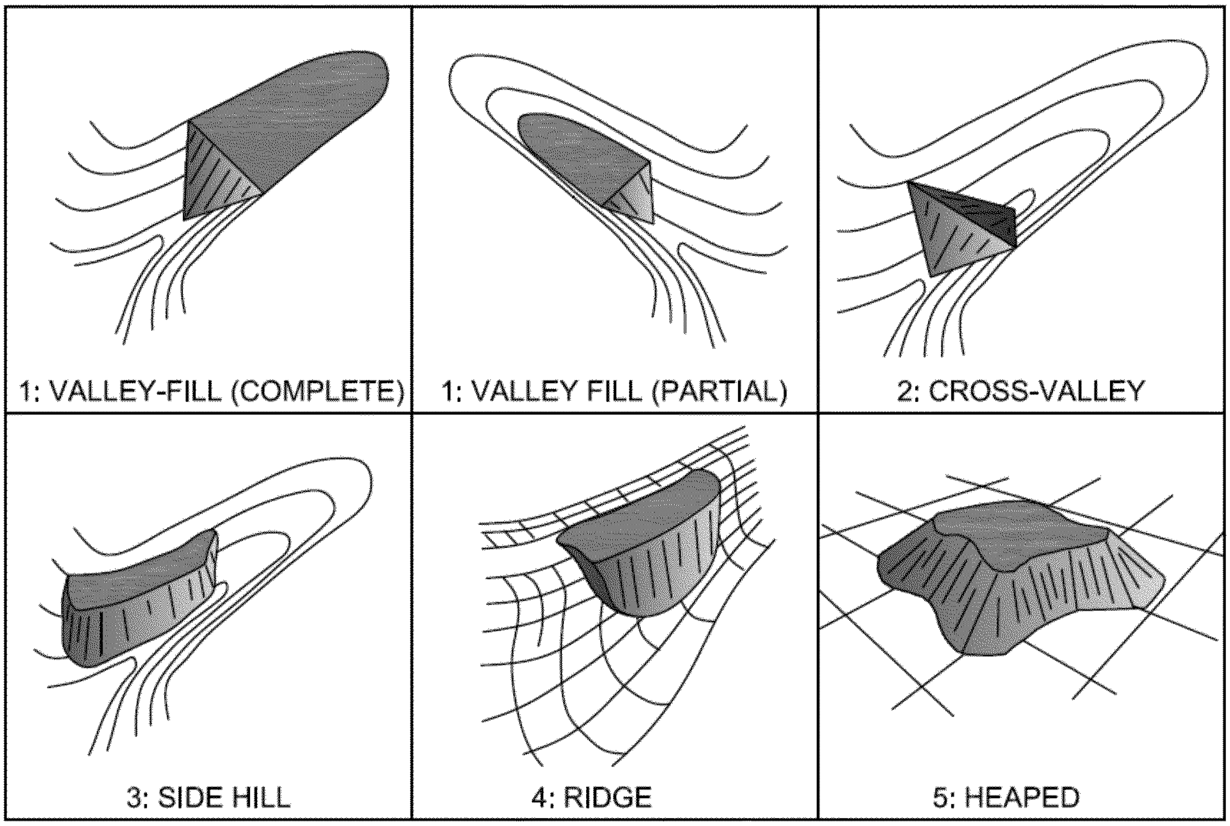

Figure 1 – Basic Waste Rock Pile Types[3]

Heaped Fills are mounds of waste rock that have slopes on all sides. Heaped Fills can also be referred to as Area Fills, Stacked Fills, or Piled Fills.

Other fills can be found that do not fit into any of the above listed categories. These fills are generally created for special purposes and sometimes incorporate more than one basic fill type. In this case, they are also referred to as Combination Fills.

Depending on site conditions, one configuration may be more suited to a particular location; however the five configuration forms are all inherently stable providing they are developed using appropriate design and construction methodology.

5. Preliminary Design Considerations

Baseline studies are conducted at proposed mine sites to collect data on important factors such as topography, climate, geology, hydrogeology, hydrology, and environmental components. Baseline data collection is expanded as appropriate on the basis of alternative waste rock disposal scenarios that are ideally developed by the environmental specialists working in conjunction with mine planners. The alternative assessments consider technical, operational, environmental, and socioeconomic factors in developing optimized layouts for the waste rock piles.

Field investigations, including reconnaissance and test pitting programs, are carried out to support preliminary waste rock pile location studies and designs. More detailed investigations, which may include geotechnical drilling programs, may also be required for subsequent engineering and environmental analyses. Soil samples are collected and tested to determine the foundation characteristics of the possible mine waste rock pile sites. Progressively more detailed evaluations of environmental considerations; including opportunities for mitigation, compensation, and for post closure end uses and reclamation, are undertaken throughout the design and permitting phases of the potential mine development.[4]

The 1995 EPA document (EPA[2]) highlighted research conducted by the British Columbia Mine Rock Pile Research Committee, which focused on the performance of mine waste piles constructed at coal mines. This research resulted in the production of the British Columbia Ministry of Energy, Mining, and Petroleum Resources (MEMPR)[4] guidelines for geotechnical investigation and design recommendations for waste piles. These design guidelines provide recommended levels of effort for investigation, design and construction for waste rock piles depending on the defined hazard level. The level of investigation, testing, design and monitoring requirements can be relatively minimal for small, low consequence piles with a 'Negligible' hazard rating. However, larger piles with a 'High' hazard rating typically require geotechnical and hydrogeological investigations, lab testing, stability modeling, comprehensive reporting, and strict monitoring and operational controls. The overall risk associated with a waste pile also recognizes the potential consequences of pile instability, and the MEMPR guidelines also suggest that key risk areas to be considered include: safety of personnel and equipment, safety of mine and public facilities and environmental impacts.

An understanding of the physical properties including particle size distribution, shear strength, durability, and hydraulic conductivity of waste rock materials is required for the design process. These parameters are influenced by the lithology of the waste rock, blasting techniques, excavation and handling methods, and placement methods. These parameters and can vary within the rock pile and can also change with time due to mechanical or chemical weathering. The design of waste dumps therefore typically incorporates conservative lower bound strength functions (representative of low density, poorly graded material) to account for the uncertainties in material composition and strength.

6. Stability Factors

The short-term and long-term stability of a mine waste rock pile is considered during the design process. Waste rock pile stability is dependent on the quality of the waste materials, the configuration of the pile (dump height/volume), pile slope, foundation slope, foundation conditions, degree of confinement, pore pressure conditions (phreatic surface) in the waste pile and foundation, climatic conditions, rate of placement, seismicity, and the construction method. It is important to characterize the foundation geology as part of the site characterization.[5] The RCRA report defines foundation types into three categories:

- Competent - highly competent bedrock or soil of equal or greater strength than the pile materials, and which is insensitive to pore pressure generation and strength reduction due to loading.
- Intermediate - intermediate material that will consolidate to gain strength with time, but which may be subject to pore pressure generation and strength loss if stressed too rapidly.
- Weak - weak material that cannot safely be loaded beyond a limiting level of shear stress, and material that does not gain strength at a significant rate by consolidation. This is frequently the case where clay layers occur within the foundation soils. Saturated fine sand foundations subject to liquefaction or high pore pressures are also included in this category.

The stability of the waste rock pile can be increased by improving foundation conditions, enhancing drainage, flattening pile slopes, including buttress fills, selective encapsulation of weaker materials within more durable materials, and by progressively updating the designs based on operational performance.

7. Construction and Operation Methodologies

Construction and operational considerations for waste rock piles can be grouped into five main categories: foundation preparation, material placement, surface water controls, monitoring, and quality assurance and quality control. Specific guidelines for construction and operations of mine rock and overburden piles have been developed for

[4] Ministry of Energy, Mines, and Petroleum Resources (MEMPR). (1991). "Investigation and Design of Mine Dumps – Interim Guidelines". Prepared by Piteau Associates Engineering Limited for the British Columbia Mine Dump Committee.
[5] Resource Conservation and Recovery Act (RCRA), (1992), "Regulation Impact on Alaska Mineral Development – Waste Rock Management". Prepared by Steffen, Robertson and Kirsten Inc. for the U.S. Bureau of Mines, Alaska.

mining operations in British Columbia as summarized by MEMPR (1991).[4] These guidelines are also relevant for operations in Alaska.

7.1. Foundation Preparation

Clearing and stripping the foundations is not usually required unless it is necessary to stockpile the foundation soils for reclamation. Soft organic soils may be removed if they present a stability concern for the pile. Alternatively, pre-lifts of waste rock material can be placed to load and consolidate the foundation soils prior to on-going placement of additional lifts.

The clearing of excess vegetation may also be appropriate to ensure good hydraulic performance in areas where drainage is required. Foundation underdrains can be constructed to collect water from a wide area beneath the waste rock pile. This water can then be directed towards a collector ditch or pond. These underdrains typically consist of large gravel or rock filled trenches.

7.2. Material Placement

Waste rock piles are built using either ascending or descending methods. Ascending construction has the advantage of each subsequent lift being built on the passively compacted (haul truck traffic) previous lift. Descending construction is typically more economical as it requires less reworking as each lift is placed from the top of the initial pile and in effect wraps around the previous lift. The constructed method is typically selected based on the location of the pile and physiography of the area.

Material can also be placed directly at the required location, referred to as 'end-dumped', or redistributed from a central location using mine equipment, referred to as 'push-dumped'. Materials tend to segregate when placed by end-dumping techniques and this may result in a zone of coarse, durable rocks at the base of the pile, and can form an effective under-drainage layer. The effects of various construction methods on segregation are described by Nichols,[6] who also describes an approach for evaluating segregation. The amount of segregation depends on lift height, durability, initial bulk gradation, and placement technique.[5]

Waste piles constructed using either ascending or descending methods using end-dump or push dump techniques can be designed and operated as stable structures as the construction method is considered in the evaluation of the material parameters for the waste pile design.

Winter operations also include protocols for managing snow and ice during pile development. This is especially pertinent for Alaskan mining operations due to the cold winter conditions. General guidelines for constructing waste rock piles in cold regions include:

- Placing waste materials in areas where the depth of snow is minimal (areas with a significant snow depth (i.e. >3 feet) should not be used for placement of waste rock. The active deposition surface should be worked evenly so that there are no large depressions that may infill with snow.
- Identifying a separate, dedicated area for snow spoil. The disposal of snow should be stored separately from the waste rock or overburden materials. The identified snow spoil areas should not include drainage courses or gullies which will be covered by waste materials later on.
- Sequencing the pile development such that winter waste placement occurs along windward exposed faces, where accumulations of snow and drifting will be the least.[4]

7.3. Surface Water Controls

Surface water control measures are required to reduce surface water run-on and run-off to minimize the potential for: saturation of the slope, development of phreatic surfaces within the pile, surface erosion, and the release of sediment. Current '*regulations and guidelines attempt to achieve two primary objectives: First, the drainage system*

[6] Nichols, R.S. 1987. Rock segregation in waste dumps. In: Proceedings of the International Symposium on Flow-Through Rock Drains, Cranbrook, British Columbia, September 8-11, 1986.

must be able to handle a calculated flood-event and, second, the system must result in a discharge of adequate quality'.[2]

Surface waters from areas up-gradient of a waste rock pile are typically diverted away from or around the waste rock pile where possible. This can be achieved by diversion channels around the pile, rock drains under the pile, or culverts under the pile. Filter relationships between adjacent materials and extreme cold weather conditions are considered when designing drains to avoid blockage. Grading of the pile crest and bench surfaces can be implemented to direct run-off away from the pile face to minimize erosion and infiltration from runoff.

Sediment control facilities are installed as appropriate to manage suspended solids. Site specific seepage or runoff collection ponds are also implemented as necessary to ensure protection of surface water and groundwater resources.

7.4. Monitoring Methods

Waste rock piles are monitored by visual assessment to identify slumping and movement within the structure. Mechanical monitoring methods such as extensometers can be used and are either mounted on the crest or buried in the slope. Displacement and settlement of the waste pile materials can also be identified with the use of electronic distance measurement instruments, settlement gauges, tiltmeters, and inclinometers. Pore pressures can be monitored by the installation of piezometers and/or standpipes. Regular monitoring of waste rock piles allows for potential stability problems to be identified early and mitigated for.

Groundwater and surface water are monitored to identify potential impacts to surrounding sensitive receptors. Monitoring systems are typically developed to confirm compliance with mine permit conditions.

7.5. Quality Assurance/Quality Control

The management approach taken towards waste rock piles will greatly influence the success and stability of a given project. Important considerations are the construction quality control and quality assurance (CQC/QA) measures in place to ensure the pile is constructed within the defined design parameters.

8. Closure and Reclamation

The principal aim of a rehabilitation program is to reintegrate land, which has been disturbed by site operations, into the surrounding landscape. It is generally intended that the quality and capability of the rehabilitated land will be similar to its pre-disturbance potential.

Waste rock pile reclamation aims to maintain long-term stability and erosion control. Thus, it is beneficial to design a waste rock pile with the eventual reclamation requirements in mind.

Reclamation of waste piles is dependent on the end land use selected for the pile area. Selection of end land uses may be constrained by the ability to establish a suitable vegetation cover; hence, selection of a re-vegetation method for a waste area is developed in concert with the development of final land use objectives.

8.1. Long Term Physical Stability

Most mine piles are progressively developed during operations by end-dumping, resulting in intermediate slope angles equal to the angle of repose, or generally about 37 degrees. Flattening of slopes to an overall slope angle of 26 degrees is generally accepted as a suitable criterion for re-vegetation as water erosion will be limited, soil creep is reduced, and infiltration is enhanced.[5]

Potential measures to achieve long-term physical stability and closure objectives include:

- Siting piles to avoid low strength foundation areas where possible

- Constructing piles using lifts and providing adequate terraces to reduce rehabilitation costs
- Constructing the rock and overburden piles with a high permeability foundation layer to prevent build-up of pore pressures
- Constructing toe berms to reduce the overall slope of the pile, and
- Slope flattening by dozing down the slopes.[5]

8.2. Re-vegetation

The natural vegetation of Alaska is mainly comprised of species adapted to harsh arctic and subarctic environmental conditions. There is a strong correlation between the nature of the vegetation and the climatic and soil conditions in the various regions of Alaska. Land rehabilitation by the establishment of persistent vegetation cover is typically planned as a three-phase operation:

1. The establishment of a rapidly growing but temporary cover of vegetation
2. The development of a slow growing and stress tolerant, but persistent, cover of vegetation, and
3. The diversification and stabilization of the vegetation cover by introduction of naturally occurring species.[5]

Factors that limit vegetation establishment differ between mining waste and soil types. Consequently, suitable disturbance tolerant plant species are selected for the rehabilitation program based upon an evaluation of the germination and growth performance of the species.

The cover of vegetation should be erosion resistant, yet sufficiently open to allow longer term natural colonization of gaps by locally indigenous species. This process of natural colonization and succession may be accelerated by the application of selected land management practices.

9. Specific Considerations for the Pebble Project

The Pebble Project is a copper-gold-molybdenum porphyry deposit located in the Bristol Bay Region of southwest Alaska, approximately 17 miles northwest of Lake Iliamna. Extensive baseline studies are in progress at the Pebble site and initial results for the period from 2004 through 2008 are reported in the Environmental Baseline Document (EBD).[7] These baseline studies are essential for guiding the plans for mine waste management at the Pebble site.

The EBD provides an overview of the topography, geology and seismicity of the site along with extensive site specific data on the climatic conditions, hydrology and hydrogeology. Extensive details are also provided for other environmental and social components that are relevant for the siting and development of stable waste piles. The siting, design, operation, and closure and reclamation requirements for waste rock piles for the Pebble project will consider the following:

- Rolling topography favorable for establishing waste rock piles on relatively flat to gently sloping terrain.
- Glaciated valleys with alluvium and glacial drift deposits in the valley bottom. Geomorphological investigations indicate the potential for weaker glacial lake deposits and surficial deposits of peat and organics. Waste dump development may incorporate pre-lifts and pre-loading techniques in some areas and include toe buttresses as appropriate to ensure the stability of the waste piles.
- Cold, windy weather during the winter months followed by wet conditions during the spring at freshet when the accumulated snow melts.
- Potential for localized permafrost conditions in the waste dump foundations
- Water diversion and collection systems to divert clean runoff to the downgradient water resources.
- Seepage management systems to protect downgradient water resources.
- Dedicated snow disposal sites.
- Seismic conditions.

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[7] The Pebble Partnership, 2011. Pebble Project Environmental Baseline Document, 2004 through 2008. Submitted to Environmental Protection Agency, December 17, 2011.

There is considerable precedent for the development of stable waste rock piles in the cold, seismically active regions of Alaska, as there are a number of mining operations in the State. The Fort Knox open pit mine is currently the largest hard rock mine development in Alaska, and it routinely manages large waste rock piles that have progressively grown over the life of the mine. The cold winter conditions are more severe than at the Pebble site, permafrost conditions are more common, and it is situated in a high seismic area. A recent environmental compliance and management systems audit was conducted for the Fort Knox mine by SRK Consulting.[8] This audit was directed by the Alaska Department of Natural Resources (ADNR), in conjunction with the Alaska Department of Environmental Conservation (ADEC) and the U.S. Army Corp of Engineers (USACE). There were no indications of waste pile stability problems for any of the large Fort Knox waste piles.

10. Conclusions

Waste rock piles can be constructed to be stable structures for the containment of waste rock and overburden spoil piles. Waste rock piles are routinely developed and managed in Alaska and Canada, but it is still necessary and prudent to complete thorough investigations and testing, detailed analyses, and comprehensive design studies, plus specific operational monitoring and surveillance. Key development activities will typically include: thorough site investigations, development of appropriate loading plans, confirmation of pile stability under static and seismic loading conditions, specifications for foundation preparations, implementation of water control/collection measures, and development of integrated closure plans. All of these activities will be necessary for any potential mining development at the Pebble site to comply with State and Federal regulations, and to meet the objectives for responsible mineral development.

[8] SRK Consulting, (2012), “Fort Knox and True North Mines Environmental Audits”, http://dnr.alaska.gov/mlw/mining/largemine/fortknox/pdf/fgmiaudi t2012ex.pdf

Author Biography

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Attachment 3
Active Metal Mines of the Fraser River Basin and Fish – Case Studies

White Paper No. 3
Topic: Fisheries and Mining
Title: Active Metal Mines of the Fraser River Basin and Fish – Case Studies
Author: Oscar Gustafson

Abstract

Mining has a long history in the Fraser River Basin starting with the Cariboo Gold Rush in the 1850s. The Fraser River is among the world's most productive salmon rivers and supports commercial, recreational, and aboriginal fisheries. Mining can create concern with respect to fisheries conservation due to potential negative effects to the land base, water quality, water quantity, and fish habitat. This paper presents case studies from four active metal mines in the Fraser River watershed as a means to assess the risk of these operations to fisheries. Information concerning mine engineering, operating details, and environmental setting are identified and assessed for this purpose. While these mines have localized effects to fish and fish habitat, there is no evidence to suggest these mines present a past, present, or future risk to the fisheries resources of the Fraser River watershed. These mines are all examples, with proven track records, of sustainable low impact operations adjacent to important fish habitat in the Fraser River drainage.

1. Introduction

Mining has a long history in the Fraser River Basin starting with the Cariboo Gold Rush in the 1850s and followed by large scale open pit copper mining in the 1960s. Currently, there are eight operating metal mines (Bralorne, Highland Valley, Craigmont, Gibraltar, Huckleberry, QR, Mount Polley, and Endako), several proposed metal mines undergoing environmental assessments (e.g. Prosperity, Ajax, Harper Creek, Ruddock Creek, Chu, and Spanish Mountain), and one metal mine scheduled to start production during 2012 (New Afton) in the Fraser River watershed. Mineral exploration activities and other types of mining (placer and aggregates) are widespread throughout the drainage.[1]

The Fraser River drains the fifth largest river basin in Canada, spanning an area of 238,000 km^2 and supporting a population of over 2.7 million people and a range of economic activities, including forestry, fishing, mining, manufacturing, agriculture, tourism, and recreation. From its source in the Rocky Mountains to its estuary on Georgia Strait near Vancouver, it has a mainstem length of 1370 km. The mean annual discharge at the mouth of the Fraser River is 3540 m^3/s. The Fraser River is among the most productive salmon rivers and fish habitats on the planet, supporting five species of Pacific salmon and 65 other species of fish.[2] Commercial, recreational, and aboriginal fisheries are conducted for Fraser River salmon throughout their adult life cycles in both saltwater and freshwater habitats. The numbers of salmon that return to the Fraser River on an annual basis are in the tens of millions. From an economic and cultural perspective, arguably the most important and iconic fish species in the Fraser River watershed is the sockeye salmon.

Mining can create concern with respect to fisheries conservation due to potential negative effects to the land base, water quality, water quantity, and fish habitat. Mine proponents cite substantial improvements to environmental assessment methods, the development of modern mining practices, comprehensive monitoring and reclamation, and improved mine regulation and oversight as tools to mitigate and/or eliminate negative environmental effects. Opponents of mine development list the documented negative effects at historic mines, such as acid rock drainage (ARD) and metal leaching, scientific uncertainty associated with sublethal effects, fish habitat losses in the mine footprint, failure of engineering designs, degradation of water quality, lack of regulatory oversight, and the legacy of closed mines as evidence of mines posing unacceptable risks to fisheries.

The purpose of this paper is to present information from several large active metal mines in the Fraser River watershed as a means to evaluate the risks of these operations to fisheries, and more broadly to assess if the modern mining practices used at these mines address issues that are frequently raised by opponents of mine development. The active metal mines selected as case studies include Highland Valley, Gibraltar, Endako, and Mount Polley, based on their large size and relatively close proximity to salmon habitat. Huckleberry was not assessed on the basis that it is sited in the Nechako hydroelectric reservoir watershed well upstream of salmon

[1] Ministry of Energy and Mines. Mineral Exploration and Mining. www.empr.gov.bc.ca/mining
[2] Fraser Basin Council. Fraser Basin. www.fraserbasin.bc.ca/fraser_basin

habitat. The Bralorne, Craigmont, and QR mines were not assessed since they are smaller operations with limited available information.

2. Case Studies

2.1. Highland Valley Mine, Logan Lake, BC

Owner / Operator: Teck Resources Limited (95%) and Highmont Mining Company (5%).[3]

Location: 60 km north of Merritt and 80 km southwest of Kamloops, BC. The entire mine site covers about 7,000 ha of land.[4]

Target Metal(s): Copper and molybdenum.

Type of Deposit: Low-grade porphyry copper-molybdenum deposit distributed over three main deposit areas.[5]

Year Mining Began: Lornex deposit (1972), Highmont deposit (1980), and Valley deposit (1983) although the area has been mined since 1907. The adjacent Bethlehem copper mine opened in 1962 and operated for 20 years.

Expected Mine Closure Date: 2026 (Valley and Lornex) and 2021 (Highmont), although ongoing exploration is expected to further extend the mine life.

Drainages in Vicinity of Mine: The Highland Valley deposit occurs in the upper part of Witches Brook, a 23 km long fourth order tributary of Guichon Creek. The tailings facility is located to the north in the upper Pukaist Creek drainage, a 17 km long fourth order tributary of the Thompson River. Guichon Creek is an 80 km long fifth order tributary of the Nicola River, which flows to the Thompson River. Mamit Lake (165 ha) is on Guichon Creek downstream of the mine. Axe Creek is an 8 km long third order tributary of Guichon Creek which drains part of the mine site. Bose Lake (21 ha) sits at the headwaters of Axe Creek. Several small lakes and ponds are distributed around the perimeter of the mine site.[6]

Fish Species Present Near or Downstream of Mine: Rainbow trout, largescale sucker, longnose dace, peamouth chub, northern pikeminnow, burbot, redside shiner, mountain whitefish, steelhead, chinook salmon, and coho salmon.[6]

Fish Streams and Lakes in Vicinity of Mine: Rainbow trout are distributed throughout Witches Brook, Guichon Creek, and Pukaist Creek, and are present in the area lakes. Chinook salmon and coho salmon spawn and rear in the lower reaches of Guichon Creek. Several fish species are present in Mamit Lake.[6]

Type of Mining: Low-grade, low strip ratio open pit, truck/shovel operation.

On-Site Ore Processing: The process plant uses autogenous and semi-autogenous grinding and flotation to produce metal in concentrate from the ore. Copper concentrate is transported in bulk 40 km to the rail yard at Ashcroft, then by rail to North Vancouver, and finally by ship to overseas smelters. The molybdenum concentrate is packaged on site for shipment.[3]

Mine Throughput: 120,000 tons per day.[5]

Waste and Water Management: Tailings are discharged to an impoundment to the north of the mine site with tailing supernatant recycled as process water. The tailings facility is approximately 10 km long and 1.7 km wide and

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[3] Teck Resources Ltd. Highland Valley Mine. www.teck.com
[4] Ministry of Natural Resource Operations. iMapBC. /www.ilmb.gov.bc.ca/content/e- services/geobc/
[5] Graden, R. 2012. Technical Report Highland Valley Copper Highland Valley, BC.
[6] Ministry of Environment. Habitat Wizard. www.env.gov.bc.ca/habwiz

supported on either end by engineered dams. The water on site is in a closed system and the water delivered to the tailings pond is recycled back to the mill.[5]

Closure Plans: Of the total disturbance of about 7000 ha, over 2000 ha have been reclaimed by re-vegetation and water bodies that have achieved end land use. Rainbow trout have been successfully stocked into several ponds within the mine site area. Testing on a wide variety of waste material, including acid base and biological leaching, has indicated that ARD will not be a concern at the mine. Upon closure, waste dumps will be re-contoured, capped with a suitable material, and vegetated in accordance with the end land use plan. The tailings impoundment will be reclaimed to its end land use objective after closure.[5]

Mitigation Measures: Acid rock drainage is not an issue for Highland Valley Copper as there are low levels of sulphide minerals present in the rock at the mine site and the rock containing the mineralization has a strong buffering capacity and will act to neutralize any acidity that is generated. Surface runoff from the site is collected and used as process water in the mill.[5]

Monitoring Program: Environmental effects monitoring is being conducted at the mine site. All water across the site is continually monitored and will continue to be monitored post closure. Seepage from the north end of the tailings facility is released to Pukaist Creek to maintain flows for the rainbow trout and aquatic insects.[5]

Risks to Fisheries: The Highland Valley Mine is sited within the headwaters of Pukaist Creek and Witches Brook, which are small streams with limited fisheries production potential. The region is arid and there is no surface discharge from the facility. Guichon Creek supports several fish species including small numbers of anadromous salmon. The stream distance between the mine site and anadromous fish habitat is more than 20 km. The Thompson River is primarily a migration corridor for anadromous salmon at its confluences with the Nicola River and Pukaist Creek.

The risks to fisheries from the Highland Valley Mine are limited to the effects of seepage on the receiving streams and reductions in flows resulting from the footprint of the mine. This is addressed through ongoing water quality monitoring. The receiving environment of the Thompson River is primarily a short duration migration corridor for salmon, such that any salmon that contribute to the fisheries resource have a very limited exposure time to any potential contaminant release. In summary, the overall risk of the Highland Valley Mine to fisheries is very low.

2.2. Gibraltar Mine, McLeese Lake, BC

Owner / Operator: Taseko Mines Limited (75%), Cariboo Copper Corporation (25%).[7]

Location: 65 km north of Williams Lake, BC and 1 km west of Granite Mountain. The total disturbed area of the mine site is approximately 2000 ha including the ore bodies, dumps, surface drainage collection system, plant site, roads, and tailings pond.[4]

Target Metal(s): Copper and molybdenum.

Type of Deposit: Mineralized reserves occur in multiple zones within the Granite Mountain batholith, in a broad zone of shearing and alteration. The deposit consists of both porphyry ores and shear zone ores. Pyrite and chalcopyrite are the principal sulphide minerals of the Gibraltar deposits.[8]

Year Mining Began: Operations began in 1972, with a number of temporary closures due to economic conditions, the most recent being 1999 to 2004. Taseko acquired its interest in the assets of Gibraltar in a transaction with Boliden in July 1999. After a period of care and maintenance, mining operations recommenced in May 2004.[8]

Expected Mine Closure Date: 2031, based on a 17-year mine life from 2004. Present reserves are sufficient for 19 years of mine operation given present copper prices.[8]

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[7] Taseko Mines Ltd. Gibraltar Mine. http://www.tasekomines.com/our -properties/gibraltar
[8] Jones, S. 2011. Technical Report on the 357 Million Ton Increase in Mineral Reserves at the Gibraltar Mine British Columbia, Canada.

Drainages in Vicinity of Mine: The Gibraltar Mine is situated within the upper Cuisson Creek drainage, a 21 km long third order tributary of the Fraser River. The tailings facility overlaps the headwaters of an unnamed tributary to Cuisson Creek starting about 17 km upstream from the Fraser River. Cuisson Creek originates at Cuisson Lake (164 ha) just over 1 km south of the mine footprint, and flows through Valerie Lake (28 ha) and Souran Lake (41 ha). Several unnamed pothole lakes occur west of the mine footprint.[6]

Fish Species Present Near or Downstream of Mine: Rainbow trout, bridgelip sucker, white sucker, largescale sucker, longnose sucker, longnose dace, peamouth chub, chinook salmon, and coho salmon.[6]

Fish Streams and Lakes in Vicinity of Mine: Rainbow trout are present throughout Cuisson Creek and in its headwater lake chain (Cuisson Lake, Valerie Lake, Souran Lake, and Rimrock Lake). Bridgelip sucker, white sucker, largescale sucker, longnose sucker, longnose dace, and peamouth chub are also present in these lakes. Stocking of rainbow trout occurred in Rimrock Lake from 1973 to 2006 and in Cuisson Lake from 1984 to 2006. Anadromous use is limited to the first 0.3 km of Cuisson Creek upstream from the Fraser River. Chinook salmon and coho salmon have been identified in this reach.[6]

Type of Mining: Open pit mining, truck/shovel operation.

On-Site Ore Processing: Ore is concentrated using conventional crushing, grinding, and flotation processes. Both copper and molybdenum concentrates are produced. Copper concentrate is shipped from the site via truck to a rail siding 18 km from the mine site. The copper concentrate is then loaded into railcars for shipment to market primarily through Vancouver. Molybdenum concentrate is packaged at the mine site and shipped by highway to Vancouver.[8]

Mine Throughput: The mine has undergone a $300 million multi-phase modernization project increasing daily milling throughput from 36,000 to 55,000 tons per day, with an annual copper production capacity of 115 million pounds. Commissioning of a 55,000 ton per day concentrator, a new molybdenum recovery facility, and mining equipment is anticipated for the fourth quarter of 2012; increasing annual copper production to a capacity of 180 million pounds.[7]

Waste and Water Management: Tailings are discharged to an impoundment to the north of the mine site with tailing supernatant recycled as process water. The Gibraltar mine has operated for 35 years from four open pits. Waste rock dumps have been developed in various areas adjacent to the open pits. Contact runoff and seepage from the mine footprint are collected and distributed to the open pits or the tailings facility. The tailings facility has a seepage collection pond and pump back system at the base of the dam. The effluent permit authorizes the discharge of water to the Fraser River (since June 2009) and the Gibraltar Pit, and the discharge of tailings to the tailings storage facility.[8]

Closure Plans: Reclamation of mine components reduces the amount of ARD produced by diverting clean runoff away from potentially acid producing rock. Typically rock dumps are resloped, capped with a glacial till cover, and revegetated. Decommissioned dumps are re-contoured to divert surface runoff.[8]

Mitigation Measures: Acid rock drainage is caused by the oxidation of naturally occurring sulphide minerals contained within the mined rock (pyrrite and chalcopyrite) from the Gibraltar deposit.

The environmental protection consists of four major components:
1) Characterization of mined materials for the potential to generate ARD
2) Management of water from the mine area
3) Reclamation and decommissioning of mine components, and
4) Monitoring of water quality in the downstream environment.

Control options for the ARD process include prevention and/or reduction of ARD reactions (e.g. through the implementation of engineered covers) as well as the collection and treatment of the resulting drainage (e.g. neutralization with lime).[8]

Monitoring Program: Water quality monitoring of the environment downstream of the mine site is routinely carried out. Cuisson Creek is the main drainage basin surrounding the mine. The farthest downstream monitoring site on

Cuisson Creek is below the confluence of the West and East branches of Cuisson Creek. Although high values of sulphate relative to the BC Water Quality Criteria are observed, water quality downstream is not substantially affected. The collection and mitigation measures being exercised appear to be working effectively in reducing downstream impacts.

The Gibraltar Mine is subject to regulation under the Metal Mining Effluent Regulations (MMER) and has discharged water to the Fraser River since June 2009.[9] The conditions associated with the MMER include compliance with water quality criteria limits, mandatory reporting and action for non-compliance, and Environmental Effects Monitoring (EEM). EEM is intended to evaluate the effects of mining effluent on the aquatic environment and in particular on fish, fish habitat, and fisheries.

The stocking of rainbow trout in the tailings pond and tailings seepage pond has been maintained since 1984. The purpose of the fish culture program is to evaluate the survival and growth patterns of stocked rainbow trout raised on natural feed in water that contains elevated levels of sulphate and molybdenum.[7]

Risks to Fisheries: The Gibraltar Mine is situated within the headwaters of Cuisson Creek, which is a relatively small stream with limited fisheries production potential. Anadromous use is limited to the first 0.3 km of the creek above its confluence with the Fraser River, while the tailings facility is located 17 km upstream. The Fraser River is primarily a migration corridor for anadromous salmon at and below this confluence. The chain of small lakes near the headwaters of Cuisson Creek are south and west of the mine footprint and support seven species of fish including a small recreational fishery for rainbow trout.

Risks to fisheries include the potential failure of the contact water collection and pump back system, which would result in the direct release of contact water that could impair downstream water quality. This is addressed through ongoing water quality monitoring. Effluent discharges are regulated under the strict conditions of the MMER.

In summary the overall risk of the Gibraltar Mine to fisheries is very low. In fact, one of the best indicators of a healthy aquatic environment downstream of the mine is the presence of several species of resident fish.

2.3. Endako Mine, Endako, BC

Owner / Operator: Thompson Creek Mining Ltd. (75%) and Sojitz Moly Resources Inc. (25%).[10]

Location: 160 km west of Prince George and 8.5 km southwest of the village of Endako. The mine site covers an area of about 2,000 ha.[4]

Target Metal(s): Molybdenum, copper, zinc, tungsten, and bismuth.

Type of Deposit: The Endako deposit is a porphyry molybdenum deposit consisting of an elongated stockwork of quartz-molybdenite veins within the Endako quartz monzonite phase of the Francois Lake Batholith. The primary ore is molybdenite with minor associated chalcopyrite, scheelite, and galena.[11]

Year Mining Began: 1965.

Expected Mine Closure Date: 2028.

Drainages in Vicinity of Mine: The Endako Mine is located on a plateau 2 km north of Francois Lake (25,799 ha), 11 km west of Fraser Lake (5463 ha), and 3 km south of the Endako River. The mine footprint overlaps the headwaters of Sweetnam Creek (7 km long), Watkins Creek (9 km long), Higginbotham Creek (1.4 km long), and several small unnamed tributaries on Francois Lake and the Endako River. The tailings facility is sited on the upper

[9] Environment Canada. 2009. Summary review of performance of metal mines subject to the Metal Mining Effluent Regulations in 2009.
[10] Thompson Creek Metals Company Inc. Endako Mine. www.endakomines.com
[11] Marek, J.M. 2011. Technical Report Endako Molybdenum Mine Located near Fraser Lake, British Columbia, Canada.

portion of a 4 km long second order unnamed tributary to the Endako River. Casey Lake (29 ha), MacDonald Lake (12 ha), and several small unnamed lakes are located north and east of the mine site area.[6]

Fish Species Present Near or Downstream of Mine: Rainbow trout, peamouth chub, longnose sucker, burbot, lake chub, leopard dace, longnose dace, mountain whitefish, northern pikeminnow, prickly sculpin, rainbow trout, redside shiner, kokanee, sockeye salmon, and chinook salmon. Fraser Lake and Francois Lake are both juvenile sockeye rearing lakes. The Stellako River at the outlet of Francois Lake and the Endako River above Fraser Lake are important spawning areas for sockeye salmon. The tailings facility is approximately 4 km upstream from the Endako River.[6]

Fish Streams and Lakes in Vicinity of Mine: Francois Lake, Fraser Lake, Casey Lake, Sweetnam Creek, Endako Marsh Lake, Savory Lake, Endako River, Stellako River.[6]

Type of Mining: Open pit mining, truck/shovel/conveyor operation.

On-Site Ore Processing: A concentrator that processes ore through crushing, grinding, and flotation circuits into molybdenum disulfide concentrate, and a multiple-hearth roasting facility that converts the concentrate into technical grade molybdenum oxide.[11]

Mine Throughput: 55,000 tons per day.

Waste and Water Management: Tailings are pumped to the tailings pond for separation of solids and water. Waste rock is placed in two active dump locations. Approximately 80% of the water used in milling is reclaimed from tailings ponds and pumped back to the mill, where it is mixed with fresh water from Francois Lake. Open pit water is discharged under conditional permit to Sweet nam Creek or is added to reclaimed water and used in the milling process.[11]

Closure Plans: Reclamation research carried out by the company has been evaluating methods of site preparation, fertilization, planting techniques, and other types of re-vegetation. An upda ted closure plan was submitted to the MEMPR in October 2010 as an amendment to the Mines Act permit for the mine plan.

Mitigation Measures: Contact water from the mine site area is directed to ponds, where it is released to the environment subject to water quality or pumped back and used as process water.[11]

Monitoring Program: Water quality monitoring of the environment downstream of the mine site is routinely carried out. Endako is subject to regulation under the MMER and has discharged seepage water to unnamed creeks that drain into Francois Lake and the Endako River. The conditions associated with the MMER include compliance with water quality criteria limits, mandatory reporting and action for non-compliance, and EEM. EEM is intended to evaluate the effects of mining effluent on the aquatic environment and in particular on fish, fish habitat and fisheries.[4,11]

Risks to Fisheries: The Endako Mine is located on a plateau at the headwaters of several small unnamed streams that drain to Francois Lake and the Endako River. These streams have very low fisheries potential. The Mine discharges seepage water to the receiving environment at two locations on the north side of the mine site area and at one site on the south side, and open pit water to Sweet nam Creek. These discharges are subject to the MMER regulations.

The risks to fisheries from the Endako Mine are very low and limited to the effects of seepage and the discharge of open pit water on the receiving streams. The effects are mitigated through the requirements of the MMER. Geographically, the mine is within several kilometres of productive salmon habitat.

2.4. Mount Polley Mine, Likely, BC

Owner / Operator: Imperial Metals Corporation[12]

[12] Imperial Metals Corp. Mount Polley Mine. www.imperialmetals.com/s/MountPolleyMine

Location: 8 km southwest of Likely and 56 km northeast of Williams Lake. The mine site covers an area of about 800 ha.[4]

Target Metal(s): Copper, gold, and silver.

Type of Deposit: Alkalic porphyry copper-gold deposit hosted within intrusion and hydrothermal breccia in diorite, plagioclase porphyry and lapilli crystal tuff.[13]

Year Mining Began: 1997.

Expected Mine Closure Date: 2023.

River Drainage in Vicinity of Mine: The Mount Polley Mine is situated on the slopes of Mount Polley in the upper headwaters of Hazeltine Creek, a 10 km long third order tributary of Quesnel Lake (27,000 ha). Bootjack Lake (268 ha) and Polley Lake (453 ha) flank the east and west side of Mount Polley and the mine site. Historical mining activities have diverted a portion of runoff from Bootjack Lake to the Morehead Creek catchment, which drains to the Quesnel River below Quesnel Lake. The tailings facility is sited on a small unnamed tributary to Hazeltine Creek about 6.5 km upstream from Quesnel Lake.[6]

Fish Species Present Near or Downstream of Mine: Rainbow trout, bull trout, longnose dace, mountain whitefish, northern pikeminnow, peamouth chub, redside shiner, burbot, kokanee, chinook salmon, coho salmon, and sockeye salmon.[6]

Fish Streams and Lakes in Vicinity of Mine: Rainbow trout are distributed throughout Hazeltine Creek, Bootjack Lake, Polley Lake, Morehead Creek, and Edney Creek. Coho salmon are present in lower Hazeltine Creek and Edney Creek. Quesnel Lake is an important rearing lake for juvenile sockeye that originate from its sockeye spawning tributaries including the Horsefly River. The footprint of the mine site area is on the slopes of Mount Polley and an unnamed tributary to Hazeltine Creek with no direct footprint impacts on fish-bearing waters.[6]

Type of Mining: Open pit copper/gold mine, truck/shovel operation.

On-Site Ore Processing: Ore is concentrated using conventional crushing, grinding, and flotation processes. Concentrates are trucked to facilities at the Port of Vancouver.[13]

Mine Throughput: 20,000 tonnes per day.

Waste and Water Management: A pipeline system conveys the tailings slurry via gravity from the Mill Site to the Tailings Storage Facility.[13]

Closure Plans: Reclamation research has been conducted on the mine site to assess site preparation, planting techniques and methods of re-vegetation. Reclamation is ongoing, including re-vegetation and hydro-seeding of disturbed areas.[13]

Mitigation Measures: Contact water from the mine site area is directed to ponds where it is collected and pumped back and used as process water.[13]

Monitoring Program: Since mine start-up in 1997, Mount Polley Mine has implemented a comprehensive water quality monitoring program that includes source areas, surface drainages, and receiving waters. Currently, water quality is monitored at seven locations in the receiving environment on a monthly basis.[14]

Risks to Fisheries: The Mount Polley Mine is located on the slopes of Mount Polley and an unnamed tributary to Hazeltine Creek, and has no direct footprint impacts on fish-bearing waters. Currently, the mine does not discharge contact water to the receiving environment. Risks to fisheries include the potential failure of the contact water

[13] Gillstrom, G. 2004. Technical Report Mount Polley Mine 2004 Feasibility Study Likely, BC.
[14] Mount Polley Mining Corp. 2009. Technical Assessment Report. July 2009.

collection and pump back system, which result in the uncontrolled release of mine water that could impair downstream water quality. This is addressed through ongoing water quality monitoring and inspections. In summary, the overall risk of the Mount Polley Mine to fisheries is very low.

3. Conclusions

The four active metal mines assessed in this white paper present very low risks to fish, fish habitat, and fisheries resources of the Fraser River watershed. The rationale supporting this conclusion is discussed as a series of key points below.

3.1. Appropriate Mine Siting

The disturbance footprints of the four mines examined in this white paper do not directly impact fish habitat that is critical to fisheries, and thus it has been concluded these mines have been sited appropriately. Proposed mine developments are subject to social and environmental impact assessment and are not allowed to proceed where the potential for significant negative effects is identified. Any direct impacts to fish habitat at these mines are addressed by regulation under the federal Fisheries Act and application of the no-net-loss of fish habitat policy of Fisheries and Oceans Canada.

3.2. Advanced Engineering Designs

No engineering design related failures that resulted in significant downstream effects to the receiving environment at any of these four mines were identified. The engineered structures located at these mine sites are the result of modern engineering design and construction standards that are determined by professional practice and legislation. They are no more likely to fail than modern high rises, hydroelectric dams, or highway bridges. Tailings dams in particular are designed to the highest standards to mitigate against seepage, slope failure, earthquakes, and floods. These four mines appear to be operating as designed and have done so for lengthy time periods, of up to 40 years at Highland Valley.

3.3. Tailings and Waste Rock Management

Each of the four open pit mines utilizes a tailings storage facility, waste rocks dumps, diversion ditches to collect site runoff, and water collection ponds. Blasting, crushing, and grinding convert hard rock to sand (i.e. tailings) to facilitate the extraction of target metals. Metals extraction utilizes process water, gravity flotation, and the application of chemical reagents. Hard rock that is determined to be unsuitable for processing is separated and deposited in discrete areas termed waste rock dumps. Modern mines are designed to dispose of both tailings and waste rock in consideration of mine reclamation and closure. Each of these four mines has comprehensive waste and water management and reclamation plans in place.

3.4. Containment of Mine Site Seepage and Surface Runoff

The four mines examined have extensive engineered water management systems in place to contain mine site seepage and surface runoff and to recirculate it as process water. The main environmental challenge at mine sites is to mitigate against the mobilization of metals and other anions to the receiving environment. Mitigation is effectively accomplished by collecting mine site seepage and surface runoff from disturbed areas and recirculating it as process water within a closed system. No evidence was identified indicating that these mines release contact water to the receiving environment other than under specific circumstances in accordance with issued permits.

3.5. Monitoring of Seepage and Discharge

The Gibraltar Mine and Endako Mine periodically release contact water to the receiving environment under effluent discharge permit conditions. Both mines are subject to regulation under the Metal Mining Effluent Regulations (MMER). The conditions associated with the MMER include compliance with water quality criteria limits, mandatory reporting and action for non-compliance, and Environmental Effects Monitoring (EEM). The results of EEM studies indicate there may be minor localized effects to aquatic biota from these discharges, although the data are inconclusive.[9,15] The Highland Valley Mine and Mount Polley Mine do not release contact water.

The Cohen Commission was formed in 2010 to investigate the collapse of the 2009 Fraser River sockeye salmon run and the long term decline of Fraser sockeye in general. The initial findings from the Commission cited marine conditions and climate change as the most likely factors contributing to the decline.[16,17] Technical studies included a review of activities in the Fraser River watershed including mining as a source of potential contaminants.[18,19] It was concluded that mining was an unlikely factor in either the short-term or long-term decline of Fraser sockeye.[16]

3.6. Ecosystem Resilience

Ecosystem resilience is the capacity of an ecosystem or species to respond to a perturbation or disturbance. For example, salmon in the Fraser River watershed must have experienced multiple extinctions during the last one million years as the result of alternating periods of glaciation . Salmon are a resilient species that originate from multiple reproducing populations, have a high reproductive capacity, display variable life histories, opportunistically colonize new habitats, and can recover from disturbance provided natural processes and variability are restored.[20,21] Recent examples include the Mount Saint Helens eruption where salmon moved to adjacent rivers to avoid degraded water quality and colonization of streams draining retreating glaciers in Alaska.[22,23] Mines, including those assessed in this paper, have a finite life and closure plans to restore pre-disturbance conditions. Salmon that may have been displaced by mining have the potential to recolonize areas following mine closure or a temporary disturbance such as an accidental spill.

3.7. Mine Regulation

The provincial Mines Act is the primary legislation governing operating mines in BC and requires a permit under Section 10 to construct or operate a mine. Proponents must file a plan with the details of the proposed work and a program for the protection and reclamation of the land, watercourses, and cultural heritage resources affected by the mine.[1] The BC Ministry of Energy and Mines and the BC Ministry of Environment have jointly developed policies and guidelines on the management of mine effluent and ARD. In summary, there is considerable regulatory oversight concerning the operation of mines in the Fraser River watershed.

4. Summary

This concludes an assessment of four active metal mines in the Fraser River as a means to evaluate the risks of these operations to fisheries. In summary, the risks to fisheries are very low and limited to the streams in the vicinity of the mine sites. These mines are all examples, with proven track records, of sustainable low impact operations adjacent to important fish habitat in the Fraser River drainage.

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Authors Biography

Oscar Gustafson, R.P.Bio., has 15 years of experience as an Environmental Assessment (EA) practitioner on resource development projects throughout the Americas and is currently a Senior EA Specialist with the Vancouver office of Knight Piésold Ltd. Mr. Gustafson's current work focus is managing baseline studies and impact assessments for resource sector clients in BC , Canada. His technical specializations include fisheries, water resources science, and Fisheries Act related permitting.

Attachment 4
Fraser River Salmon and Mining Review through 2012

White Paper No. 4
Topic: Overview of Mining in Fraser River Basin
Title: Fraser River Salmon and Mining Review through 2010

Authors: Bruce S. Ford, MRM, R.P. Bio[1] and Jennifer Sarchuk, Dip.T., B.Sc.[1]

Executive Summary

This report provides a review and summary of the existing data on salmon stocks and resource development within the Fraser River watershed with a focus on mining activities.

The Fraser River is approximately 1400 km long from its headwaters in the Rocky Mountains to the Georgia Strait at Vancouver. The Fraser River supports all five species of Pacific salmon (sockeye, chinook, coho, chum and pink) and 53 other species of fish (McPhail and Carveth, 1994). The watershed is home to 2.7 million British Columbians, which includes 91,600 aboriginal peoples from 91 First Nations (BC Stats, 2006). The major resource activities in Fraser River watershed include forestry, mining, farming and fishing. Urban development is also a major activity in the watershed.

In the Fraser River watershed, sockeye, chinook, chum and pink salmon stocks have shown an overall trend to increasing escapement since from the early 1950s with runs peaking in the early 2000's. However, coho peaked in the early 1980s and the number of coho has declined since then. Coho are more susceptible to development within the watershed because they favour small streams for spawning and their distribution coincides with the section of the Fraser River watershed with the greatest disturbance from development. Overall the four major watersheds in the Fraser Basin – Thompson, Quesnel, Nechako, and Stuart show the same trends as total numbers in the Fraser River watershed.

Mining is an important industry in British Columbia (BC) with a history dating back to the Fraser River Gold Rush in the 1850's. In 2011, there were 27 active mines operating in the Fraser River Watershed. Many of these are mines extracting copper, molybdenum and other metallic minerals. Mining operations have the potential to affect water quality and fish habitat, but a review of the literature and available public data on mining in the Fraser River watershed shows that there has been no noticeable adverse effect on the overall salmon population. Since the mid-1950's, there has been an upward trend in both mine production and salmon escapement, with both the landed value of sockeye salmon and the amount of mined ore increasing over time.

In conclusion, salmon in the Fraser River have increased in abundance between the rock slide at Hell's Gate in 1913 and the early 1990's. At the same time the production of precious and base metal mines has also significantly increased, demonstrating that mining activities have not had a direct effect on overall salmon production. However, reports do indicate that some salmon populations need special attention, such as the interior Fraser coho and the Sakinaw and Cultus Lake sockeye populations in the lower Fraser Watershed that have experienced declines in recent years. The consensus is that wild salmon populations of the Fraser River are at risk from several factors, but our findings do not identify mining as a factor affecting salmon stocks in the Fraser River Basin.

Based on this review of the empirical evidence, mining activity in the Fraser River watershed over the last 50 years has not had a negative effect on salmon populations and the commercial salmon fishery. Also, there have been no large scale effects from mining on salmon habitat. The evidence also shows no relationship between salmon price and mining activity.

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[1] *Contact: AECOM 3292 Production Way, Burnaby BC, V5A 4R4, Phone: 1-604-444-6400*

1. Introduction

This white paper provides a review and summary of the existing data on salmon stocks and resource development within the Fraser River watershed with a focus on mining activities.

Resource development began in the Fraser River watershed in the 1800s with logging, placer mining and hardrock mining. As the population of BC grew, agriculture and urban development, along with the necessary transportation corridors, expanded throughout the watershed. This review is focused on mining and fishing activities since 1954 as this date generally coincides with an increased effort in stock specific management (largely chinook and sockeye) and collecting stock specific data on salmon returns to watersheds and streams, particularly in the Fraser River. Management of the commercial fishery of Fraser River stocks is particularly complex due to the species mix in the fishery and the sub stocks associated with each species. Different species and stocks return at different times and are able to support different exploitation rates. Data collection for some species like chum and coho was not regularly collected until the 1970s in some sub-watersheds. Also, the record keeping for mining activity in BC became more reliable in the mid-1950s.

This study has been an integration of existing data on fish, mining and other resource development activities available for the Fraser River watershed. Fisheries and Oceans Canada's (DFO) New Salmon Escapement Database (NUSEDs) escapement data and the province's Minfile database on mining activities were the main data sources used to complete this analysis. Data from other sources were also collected. General programs that have been reviewed include the Fraser River Action Plan, Fraser River Estuary Management Program, reports prepared by DFO and published under the Canadian Science Advisory Secretariat, the Fraser Basin Council and the Pacific Salmon Commission. The Fraser River watershed has been extensively studied for more than 30 years. In 1991 the Fraser River Action Plan was established by the federal government, which funded a wide range of ecological and social studies within the watershed. The program culminated in the formation of the Fraser Basin Council in 1997, which is mandated to advance sustainability throughout the entire basin. The long-term vision of the Fraser Basin Council is "to ensure that the Fraser Basin is a place where social well-being is supported by a vibrant economy and sustained by a healthy environment – a true reflection of sustainability".

We also researched a wide variety of sources in order to identify factors that the public, non-government organization, government fisheries managers and researchers consider to be important influences on salmon populations in the Fraser River. Along with reports specifically referenced at the end of this document we have searched for and reviewed readily obtainable reports from government and non-government sources. The spreadsheet in Appendix A provides a list of the data sources and reports that were reviewed during the course of this study. The main sources searched included:

- DFO library and databases
- Pacific Scientific Advisory Review Committee Reports
- T. Buck Suzuki Environmental Foundation (www.bucksuzuki.org)
- BC Government web sites
- David Suzuki Foundation (www.davidsuzuki.org)
- Sierra Club of Canada (www.sierraclub.ca/bc)
- Pacific Fisheries Resource Conservation Council (www.fish.bc.ca)
- Cohen Commission Technical Reports (www.cohencommission.ca/en/)

2. Fraser River Watershed – Background

The Fraser River is approximately 1400 km long from headwaters in the Rocky Mountains on the eastern boarder of BC to the Georgia Strait at Vancouver (Map 1). The entire watershed covers approximately 25% (240,000 square kilometres or 91,892 square miles) of BC and has a mean annual flow of 3,600 m^3/s (127,133 ft^3/s). The Fraser River watershed covers a wide range of ecological conditions including alpine tundra and pine forests, grasslands and desert-like canyons, old growth rainforest and lowland valley. The Fraser River supports all five species of pacific salmon (sockeye, chinook, coho, chum and pink) and 53 other species of fish including steelhead, rainbow trout, bull trout, Dolly Varden and white sturgeon (McPhail and Carveth, 1994).

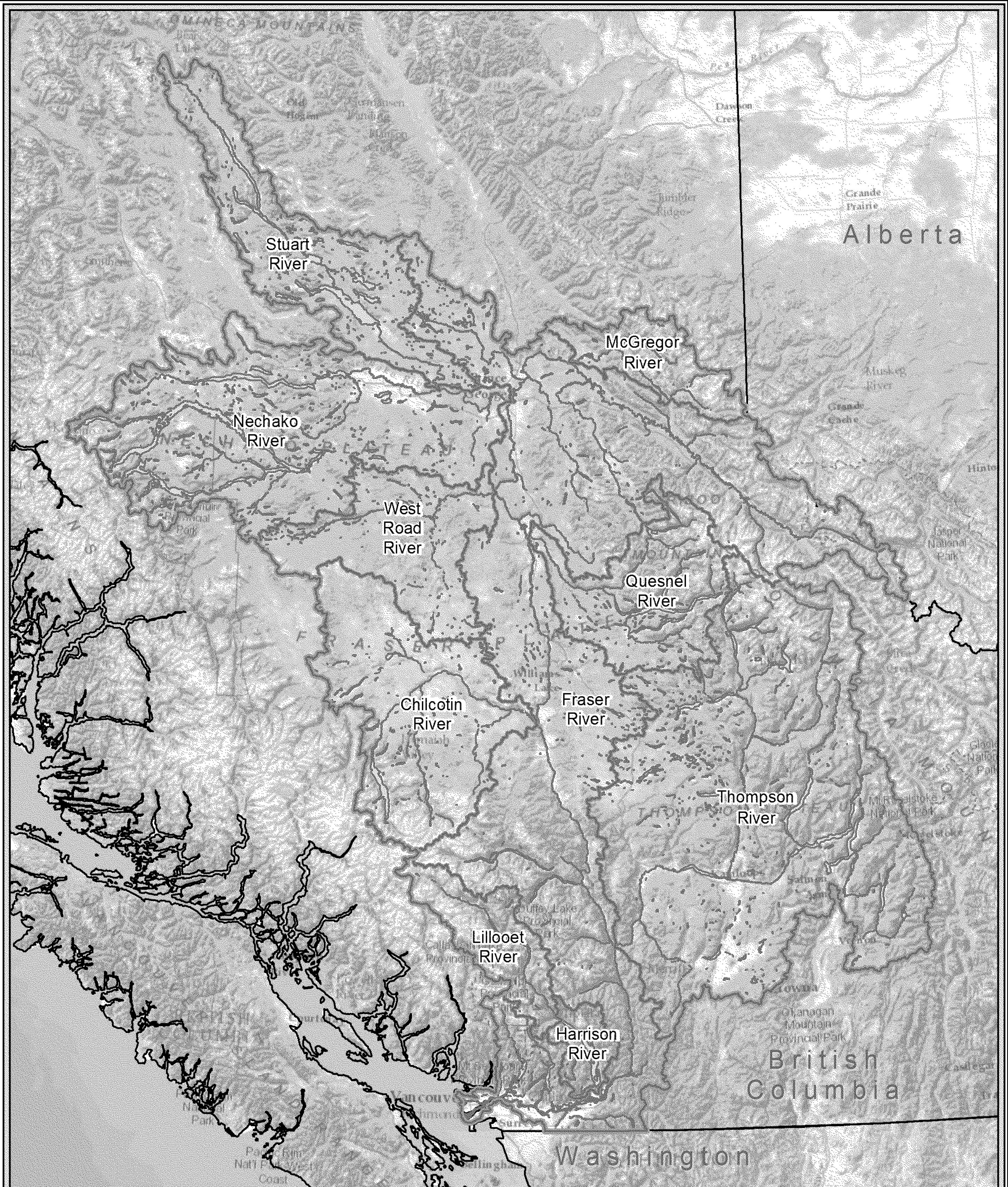
The watershed is home to 2.7 million British Columbians including 91,576 aboriginal peoples from 91 First Nations (BC Stats, 2006). The Basin contributes 80% of the provincial economic output and 65% of total household income (Fraser Basin web site: www.fraserbasin.bc.ca). Major resource activities in BC take place in the watershed, including fishing, forestry, mining, and farming, and are discussed below.

- Fishing: Commercial fishery takes place along BC's west coast for stocks that originate in the Basin; and First Nation and recreational fisheries take place throughout the watershed. Commercial salmon catch of Fraser River for sockeye salmon stocks from 2007-2009 were closed due to low returns; however, in 2010 the sockeye salmon catch of 11,945,000 fish was one of the highest on record (Pacific Salmon Commission data). Ceremonial and subsistence fishing is an important component of the First Nation fishery on the Fraser River.
- Forestry: 21 million hectares of forested lands supporting an allowable cut of 62 million m^3/year (estimated from statistics provided at www.for.gov.bc.ca/hts/aactsa.htm). Since the 1970's forest harvested area has been less than 10% of the watershed, whereas mountain pine beetle disturbance is up to 90% in some affected areas of the Watershed (Nelitz et al 2011).
- Farming including ranching and orchards: Approximately 2.4 million hectares of farmland in the Fraser Watershed, supporting about half of all BC farms.
- Mining: Approximately 60% of BC's mineral production has been from mines in the Fraser River watershed, with 91 mines that have operated between 1954 and 2005. Many of these mines have been large producers of copper, molybdenum and other metallic minerals. In 2011, 27 major mines and many small placer mines were active in the area.
- Other Industries: 10 pulp and paper mills, 15 wood preservation facilities, 17 cement and concrete facilities, 37 municipal wastewater treatment plants, 83 municipal and industrial landfills, several hydroelectric facilities (large and small scale).

3. Fraser River Fish Stocks

3.1 History

In 1913 a major rock slide in the Hell's Gate Canyon, 200 km upstream of the Fraser River estuary, significantly impacted the salmon runs trying to reach mid and upper Fraser River streams. The slide was caused by rail road construction activities taking place above the River. This event deposited a large volume of rock in the river creating a velocity barrier that has had a long lasting effect on the Fraser River commercial salmon, in particular the sockeye population. Some researchers suggest that sockeye runs are still recovering from this disaster. While sockeye salmon return to spawn every summer, the population has a dominant year that is repeated every four years.



Basemapping from ESRI.

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Fraser River Basin

Fraser River Watersheds

Pebble Mine

Major Watersheds of the Fraser Basin

July 2012
Project: 60264275

AECOM

Map 1

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1913 was a return year for the dominant cycle of sockeye salmon in the Fraser River. Prior to 1913, this dominant cycle year resulted in estimated escapements of 5 to 13 million fish and catch estimate in the dominant years from 1901 to 1909 ranging from 5 to 35 million sockeye (DFO 2001).

While recovery of some stocks began in the 1920s and 1930s, sustained increases only came after the construction of fishways in the Hells Gate Canyon along with a five-year fishing closure on early and mid-season run timing groups from 1946 to 1959 (DFO 2001). More recently, the 1912 cycle line or 2002 returns have generally been the dominant cycle year. with the exception of 1997 and 1998 when the 1997 returns (1913 cycle line) was approximately the same as the 1998 escapement. However, in 1998 far fewer sockeye reached the spawning grounds than was anticipated based on hydroacoustic counts on the Fraser River at Mission and from test fisheries at the mouth of the Fraser River. An inquiry was formed to determine the fate of the "missing fish" which was estimated at 3.5 million sockeye. The reasons for the disappearance of these fish was never conclusively determined but factors that were identified included natural causes brought on by high water temperatures and other factors such as over-fishing in the river and inaccuracies in the system used to estimate escapements at the mouth of the Fraser River. Habitat limitations or presence of mining activities were not identified as causative factors for the missing fish.

Figure 1 provides a graph of the total salmon escapement to the Fraser River watershed annotated with significant dates related to salmon management within the watershed. The histogram shows the relative contribution of each of the commercial species to the total escapement. Prior to the 1950s enumeration focused almost entirely on sockeye, hence the lack of information on the other 4 species prior to 1951. Figure 1 shows that there has been an increase in escapement numbers since 1938.

3.2 Salmon Escapement and Catch

Escapement numbers from DFO's NUSEDs database were used as the measure of stock because it is the most comprehensive summary of escapement numbers available (i.e. those fish that make it past the various fisheries to the spawning grounds), including counts on individual spawning streams. However, total returns would be a more appropriate measure of population as it is the sum of all the fish returning including those caught in the various fisheries plus those that escape the fishery to the spawning streams. Catch statistics for commercial, first nations and recreational fisheries are not easily attributed to the specific watersheds the fish belong to, therefore the total returns to the Fraser River and its sub watersheds are difficult to compile and the accuracy of the numbers could vary from year to year. A similar caution must be applied to the escapement data and the estimates of total escapement to the Fraser or its various sub-watersheds.

A number of factors influence the stream counts that contribute to estimates of total escapement, particularly for coho and chinook salmon. DFO's ability to survey streams is constrained by its annual budget, which has often resulted in different numbers of streams being surveyed from year to year. Escapement numbers have been collected through a variety of methods for most species over a fairly long time and the data collected may not be a good estimate of total escapement. However, data collection has been carried out in a fairly systematic manner over the years and the NUSEDs data is likely the most accurate reflection in the trends in escapement levels over the years. The exception to this is sockeye salmon. Because of the efforts of DFO and the Pacific Salmon Commission, there are specific efforts to determine the origin of sockeye salmon caught in the various fisheries as the adults head to their spawning streams and counting fish on the spawning streams is comprehensive and fairly consistent from year to year. The effort to collect catch and escapement data for sockeye salmon allows for the development of an estimate of the total adult population returning to the Fraser River.

Figures 2 through 6 provide escapement numbers for the entire Fraser Basin broken down by salmon species. The graphs provide the actual escapement numbers and show the four year moving average of escapement. Moving averages are often used on time series data that have high variation from time period to time period to provide a smoother line to more easily identify any underlying trend in the data. A four year moving average was selected for this data because of the life cycle characteristics of the major salmon species. The dominant age group (93%) of returning sockeye and chinook salmon is 4 year olds. Pink salmon returning to the Fraser River are 2 years old and return on the odd years. The dominant age of returning coho and chum salmon is 3 and 5 years, respectively.

Sockeye, chinook, chum and pink salmon stocks have shown an overall trend to increasing escapement between the 1950s (Figures 2 – 5) and the early 1990s. However, the data shows that coho have experienced a decline in escapement since the 1970s (Figure 6). Studies into the cause of the coho decline (DFO 2002) found a strong correlation between increasing agricultural and urban land use, and increases in the density of road networks. Coho favour small streams for spawning and their spawning distribution, from the estuary up to the Thompson River watershed, is in the area of greatest human disturbance for urban development within the watershed. The Species At Risk Web site (www.speciesatrisk.gc.ca) also lists over harvesting and poor marine survival as contributors to the decline in coho stocks. Mining was not mentioned as a factor.

3.2.1 Breakdown by the major watersheds

Using the location of the major sockeye rearing lakes as a guide we identified four major watersheds for closer analysis of Pacific salmon escapement. The four major watersheds included the Thompson, Quesnel, Nechako and Stuart (Figure 1). Figures 7 through 19 summarize the overall escapement to each of those watersheds and the escapement for individual species, sockeye, chinook, and coho (where present). Pink and chum escapement data is not collected in a way that allows us to provide a breakdown by watershed but both species generally do not spawn upstream of the Thompson River. Note that while the data for sockeye is fairly consistent for all watersheds, the escapement data for some of the other species was not systematically collected and in some cases did not start until the 1970s.

Overall each of these watersheds shows the same trends as was observed in the Fraser River as a whole. In each of the selected watersheds, salmon stocks in the 1990s were generally higher than they were in the 1950s and 60s; however by the early 2000's most stocks showed some degree of decline. Coho in the Thompson River watershed are the exception to this, having experienced a significant decline from the late 1980s thought the late 1990s as described above.

3.2.2 Total Returns of Sockeye Salmon

Figure 20 provides the data on the total returns of sockeye salmon returning to the Fraser River and includes the number of fish caught in the commercial and native fishery and the escapement numbers presented above. Returns consist of both catch and escapement. This graph shows that, on average, sockeye returns in the dominant cycle years, 1993 and 1994, 1997 and 1998, 2001 and 2002, 2005 and 2006, have decreased since the 1990's. This fact was included in the Fraser Basin Council's 2006 report (Fraser Basin Council, 2006), which attributed the sockeye decline to high in-river water temperatures during the spawning migration causing higher than expected mortality. In 2009, a dominant cycle year, sockeye returns were very low at approximately 1.2 million fish and the commercial fishery was closed. However, this was followed by a record return of almost 35 million fish in 2010 that was the highest number of returns dating back to before the 1913 Hells Gate rock slide.

Figure 21 summarized the exploitation rate for Fraser River sockeye which ranged from 60% to 80% through the early 1990's. Since 1998 exploitation rates have dropped to between 10% and 50% equating to catches ranging from 0.5 to 4.2 million fish (data supplied by DFO, 2006). In 2007, 2008 and 2009, harvesting of sockeye was very limited due to the small return numbers ranging from 1.2 to 1.3 million fish. The decreasing harvest rates of Fraser River sockeye in recent years can be attributed to DFO's increased efforts to protect some depressed stocks. In particular, the Fraser River coho, steelhead trout, some lower Fraser sockeye runs (Sakinaw and Cultus Lake) and the late run Fraser River sockeye have been the focus of increased conservation measures. Conservation efforts have included significant reductions in the exploitation rates of the depressed stocks, which because of the mixed stock fishery on the Fraser has resulted in an overall reduction in the exploitation rate of all Fraser River sockeye stocks (DFO 2005).

4. Mining Industry in the Fraser River Watershed

Mining is an important industry in BC with a history dating back to the Fraser River Gold Rush in the 1850's. Since then BC has been one of the world's major mining regions (Ministry of Energy Mines and Petroleum Resources, 2007). The mining data for the Fraser River Watershed was extracted from the BC government Minfile database (www.em.gov.bc.ca/Mining/Geolsurv/minfile) and the Cohen Commission Report titled "Potential Effects of Contaminants on the Fraser River Sockeye Salmon" (MacDonald et al. 2011). Mining in the Fraser Basin consists of the following:

- 67 mines identified as past producers dating back to 1954, of which 51 were metal mines. Many of these mines have produced copper, molybdenum, gold, and silver.
- 25 mines were identified as operating metal and mineral mines within the area.
- There are 7 operating mines in the Upper Fraser, 3 operating or inactive mines within the Quesnel River Area, 3 mines within the Nechako/Stuart/Tremleur Area, 2 metal mines and 4 non-metal mines within the Lower Thompson River Area, 1 mine within the North Thompson, and 3 non-metal mines in operations within the South Thompson, 1 mine in the Harrison/Lillooet Area, and a facility producing shale and clay within the Chilliwack/Cultus Lake Area.
- Historically, mines in the Fraser River watershed have accounted for over 60% of BC's mineral production.

Table 1 summarizes the overall production between 1954 and 2005 while Table 2 lists the active mines and Table 3 lists the past producing mines of the Fraser River Basin. Map 2 provides the locations of all past and current mines within the Fraser River watershed.

Base and precious metal mines that were in operation in or after 1954 have mined a total of 210 million tonnes of ore, while the mines that are currently producing have mined a total of 1.8 billion tonnes since 1954, for a total production of 2 billion tonnes. This production resulted in the following commodity production between 1954 and 2005:

Table 1. Commodity Production 1954-2005

Mine Status	Gold (kg)	Silver (kg)	Copper (kg)
Past Producer	199,000	697,000	731,000,000
Producer	21,000	1,405,000	5,263,000,000
Total	**220,000**	**2,102,000**	**5,994,000,000**

Basemapping from ESRI.

Legend

Active Metal Mines

Metal Mines - Past Producer

Fraser River Basin

0 50 100
Kilometers
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PCS Albers

Pebble Mine

Active and Historic Metal Producing Mines

July 2012
Project: 60264275

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Map 2

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Table 2. Active Mines of the Fraser River Basin

Name	Primary Commodity	Secondary Commodity	Quantity Mined (tonnes)
Metal Mines			
Highland Valley Copper (Valley and Lornex)	Copper	Molybdenum	1,459,337,105
Craigmont	Magnetite	Copper	33,416,917
Bralorne	Gold		4,981,419
QR[2] Gold			1,128,427
Mount Polley	Copper	Gold	74,882,990
Gibraltar	Copper	Molybdenum	582,338,830
Huckleberry	Copper	Molybdenum	119,697,099
Endako	Molybdenum	Copper	391,809,219
Copper Mountain	Copper	Gold, Silver	2,400,000
Industrial Minerals			
Falkland	Gypsum	Anhydrite	1,364,841
Richmix Fireclay	Shale	Clay	
Sumas	Shale	Clay	5,500
East Anderson River	Granite	Dimension Stone	
Harper Ranch	Limestone		7,584,903
Walhachin Quarry	Railroad Ballast		
Red Lake	Fullers Earth	Diatomite	
Buse Lake	Volcanic Ash	Silica	407,041
Pavilion Limestone	Limestone	Aggregate	4,311,529
Ranchlands	Zeolite		
Ash	Aggregate		
Mount Meager	Pumice	Pozzolan	
Nazko	Aggregate	Pumice	24,800
Dahl Lake	Limestone	Aggregate	651,309
Dome Creek	Slate	Flagstone	
Giscome	Limestone		234,988

[2] *Historic mine that reportedly went back into production in 2010 but BC Minfile (http://minfile.gov.bc.ca) does not include any recent production data for this mine*

Table 3. Past Producing Mines of the Fraser River Basin Since 1954 to 2005

Name	Primary Commodity	Secondary Commodity	Quantity Mined (tonnes)	Name	Primary Commodity	Secondary Commodity	Quantity Mined (tonnes)
Metal Mines							
Lumby	Mica	Graphite	1,991	Victor	Copper		27,215
St. Paul	Silver	Gold	392	Alwin	Copper	Silver	233,076
Silver Bell (L. 4329)	Silver	Gold	14	Bralorne	Gold	Silver	4,981,419
Lucky Coon (L. 5231)	Lead	Zinc	30	Pioneer (L. 456)	Gold	Silver	2,314,459
Mosquito King	Silver	Zinc	419	Eagle Mercury	Mercury	Silver	113
Ex 1	Lead	Zinc	274	Birkenhead	Jade/Nephrite	Talc	100
Energite	Lead	Silver	36	Brett	Gold	Silver	9,177
Dimac	Tungsten	Wollastonite	18,350	Silverquick Mine	Mercury		1
San	Silver	Lead		Taylor-Windfall	Gold	Silver	555
Samatosum	Silver	Gold	353,129	Blackdome	Gold	Silver	327,323
Ladner Creek	Gold	Silver	1,108,425	Boss Mountain	Molybdenum	Copper	7,588,020
Pride of Emory	Nickel	Copper	4,319,976	Providence	Silver	Lead	28
Seneca	Zinc	Copper	260	(PL. 7139)	Gold		4,118
Channel Bar	Gold	Silver	7	Skarn	Silver	Gold	
Ajax (West)	Copper	Gold	4,053,706	QR	Gold	Silver	1,128,427
Ajax (East)	Copper	Gold	4,036,771	Antler Creek	Gold		666
Cliff (L. 899)	Magnetite	Iron	5,524	Quesnel	Diatomite		15,200
Afton	Copper	Gold	40,791,247	Emerald Glacier	Zinc	Silver	8,342
Hat Creek	Coal		10,878	Mouse Mountain	Copper	Silver	20
Bethlehem	Copper	Silver	96,324,510	Hannador	Gold		70,134
Highmont	Copper	Molybdenum	37,247,399	Island Mountain	Gold	Silver	699,536
Aberdeen (L. 960)	Copper	Silver	1,674	Mosquito Creek	Gold	Silver	92,826
Enterprise (L. 651)	Silver	Gold	71,313	Cariboo Gold Quartz	Gold	Silver	1,951,944
Turlight (L. 4841)	Copper	Silver	187	Genesis	Jade/Nephrite	Gemstones	34
Mary Reynolds (L. 674)	Silver	Lead	136	Pinchi Lake Mercury	Mercury		2,046,460
Industrial Minerals							
Westwold	Marble	Dimension Stone	4,809	Agassiz Lime	Limestone		21,802
Valemont	Silica		150	Valley Granite	Granite	Building Stone	68,325
Gilley Quarry	Granite	Dimension Stone	2,036,477	Cayoosh Creek	Granite	Dimension Stone	300
Sumas Fireclay	Shale	Clay	55,000	Frenier	Perlite	Pozzolan	6,500
Pitt River Quarry	Granite	Dimension Stone	51,054	Maeford Lake	Marble	Dimension Stone	148
Popkum Limestone	Limestone		113,761	Lot 906	Diatomite		22,074
Agassiz Granite	Granite	Dimension Stone	277	Purden	Limestone		20,000
Cheam Marl	Marl		586,512	Quarry	Limestone	Railroad Ballast	3,350,568

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4.1 Mining and Salmon

Mining operations are known to have the potential to affect water quality and fish habitat, but a review of the literature presented in Appendix A shows that mining in the Fraser River watershed has not had a noticeable effect on the overall salmon population. Figure 22 overlays salmon escapement and total tonnes of ore mined (precious and base metal) from the 1950s to 2005. Both data sets show considerable variation from year to year. To smooth this variation and more clearly show the trend in escapement and ore mined a four year running average of both are included on Figure 22. As can be seen, for more than 60 years, there has been an upward trend in both mine production and salmon escapement since the mid-1950s through to 2002. The five year average of tonnes of ore mined and total salmon escapement in the Fraser Watershed around 1960 and 2000 are presented in Table 4.

In the 40 years from 1960 to 2000 there has been a 100-fold increase in the tonnes of ore mined while over the same time period the escapement to the Fraser River has increased approximately 5 fold.

Table 4. Fraser Watershed, Salmon Numbers and Mined Metals, 5-year Average for Selected Periods

Year	Mined Metals (tonnes of ore)	Total Salmon Escapement (# of fish)
1958	408,062	3,674,083
1959	356,057	2,867,244
1960	449,515	954,966
1961	853,381	2,399,463
1962	2,133,276	1,927,592
Average	**840,058**	**2,364,670**
1998	140,142,730	8,410,979
1999	81,603,600	8,509,219
2000	99,107,200	3,319,352
2001	91,671,796	27,329,029
2002	36,900,000	12,616,659
Average	**89,885,065**	**12,037,048**

Of the four watersheds selected for more detailed studies, the Thompson River watershed shows the greatest exposure to mining since 1954, followed by the Quesnel Watershed. When considering only active mines, the Nechako, Quesnel and Thompson watersheds support two mines each. Highland Valley Copper in the Thompson drainage actually operates both the Valley and Lornex mines. The seventh mine, Gibraltar is in a small watershed that is a direct tributary to the Fraser River mainstem.

4.1.1 Fraser River Mining Issues Identified

Past and current mining related issues associated with active mines in the Fraser River watershed that have received some profile includes:

- In 1982 there was a cyanide release from the Caroline mine affecting tributaries to the Coquihalla River which is a tributary to the Fraser River. The mine is now closed.
- Loss of habitat for resident trout species in the immediate mine site from the development of the Highland Valley mine. Offsetting this has been the success that the mine has had at turning old tailings ponds into productive trout habitat (1970s). Further investigation found that water taking for farming activities has had a significant effect on sections of stream used by coho salmon.

- A campaign staged by the Sierra Club of Canada opposing the Huckleberry Mine's application to discharge effluent from a tailings pond directly into Tahtsa Lake.

A study prepared by Marmorek *et al.* (2011) consolidated the findings of the various technical reports prepared for the Cohen Commission to conduct an assessment of the potential cumulative effects of various factors likely to affect sockeye productivity. The study looked at various stages of the sockeye life history including the early freshwater stages (incubation, emergence and rearing) and the last life stage, the return migration and spawning which includes significant time in freshwater. The study found that factors including forestry, mining, hydro projects, urbanization, agriculture, water use, contaminants, density dependent mortality and predators do not appear to be affecting productivity at the early life history stage. Climate change was considered a possible factor and there was not enough information to make any conclusions about the effect of pathogens. They also concluded that it was unlikely that pre-spawn mortality, habitat changes and contaminants were responsible for the overall pattern of declining sockeye productivity observed since the mid 1990s.

5. Summary of Other Findings on the State of Fraser River Salmon

5.1 2004 Southern Salmon Fishery Post Season Review (Williams 2005)

The federal government committee report summarised previous issues related to sockeye. Studies in recent years focused on natural environmental factors and commercial fisheries management issues as the significant factors influencing the number of sockeye salmon available to the commercial fishery and reaching the spawning grounds. Particularly climate driven ocean productivity, high water temperatures in the Fraser River during migration and poor estimates of in-river catches have been consider the likely factors affecting salmon populations. The DFO's Policy for the Conservation of Wild Pacific Salmon, 2005 identified that habitat for Pacific Salmon is under increasing pressures from human development and specifically identified urban, agriculture and forestry developments as the three primary causes of increased pressure. Mining was lumped in with "other industrial activities" and none of these activities were identified as having a significant adverse effect on salmon populations.

5.2 T. Buck Suzuki Environmental Foundation

The T. Buck Suzuki Environmental Foundation is an organization devoted to the protection of fish and fish habitat. The foundation's web site highlights mining as an activity that can degrade fish populations and fish habitat. The web site identifies three specific mines where mining has impacted fish, which includes the Caroline Mine (Ladner Creek) in the Coquihalla R. watershed, a tributary to the Fraser River. The Caroline mine had a cyanide spill in 1982 which caused a fish kill that extended down to the Coquihalla River. This mine was closed by the mid-1980s and was not subject to current regulatory standards. The web site suggests that mining has its environmental problems and that environmental impacts must be measured and addressed before any prospective mine is allowed to go into operation. The organization's web site focuses on forestry, urban development including sewage discharge, fish farms, hydroelectric projects and pollution in general as the major factors facing salmon populations today.

5.3 Sierra Club of Canada, BC Chapter

In 2006, the Sierra Club released a report (Levy 2006) on declines in the BC sockeye salmon population. The report focused on select sockeye salmon stocks throughout BC, including some of the Fraser River stocks. The report supported the conclusions provided in the Fraser Basin Council 2006 report that the returns of the dominant cycle lines have declined since the early 1990's. The report did not identify mining as a cause of declining salmon stocks, but rather attributed those declines to:

- Reduced marine survival;
- Evidence suggesting climate change has affected sockeye marine migration timing and patterns and water temperatures in the Fraser River reducing overall survival rates of fish; and
- Mixed stock fisheries interception where weaker sockeye stocks are caught in fisheries for more robust or enhanced sockeye stocks.

Because the Sierra Club report was issued in 2006, it did not take account the enormous increase in sockeye salmon returns which occurred in the Fraser River system in 2010, which far surpassed all records since 1913.

5.4 Water Quality

Water Quality monitoring on the Fraser has been in place for 15 years. Gray and Tuominen (1999) reviewed water quality analysis of the Fraser River and reported that the primary parameters show that decreasing water quality in recent years is related to pulp mills and municipal waste water treatment plants. The analysis indicated that levels of trace metals frequently exceeded guidelines set by the Canadian Council of Environmental Ministers (CCME). While trace metals are often parameters associated with mine water discharge, Gary and Tuominen (1999) attributed the observed exceedences to trace metals that occur naturally in the sediments which become mobilized during higher flows and represent background conditions in the river. This analysis included the trace metals that are most often linked to mining such as mercury, lead, selenium, zinc, cadmium and chromium.

More recent water quality data summarized for the Fraser River, as reported in Environment Canada *et al.* (2007) indicate that the water quality in the mainstem was rated between fair and excellent. The primary influences on water quality were identified as municipal wastewater effluent, pulp mills and forestry. The two sites reported on the Thompson River rated as marginal to fair with agriculture, wastewater effluent, urban development and forestry being the main influences on water quality. Although the report identified several large mines in the Thompson River watershed, it did not identify mining activity as a primary influence on water quality.

A report prepared for the Cohen Commission (MacDonald et al. 2011) compiled a detailed inventory of potential aquatic contaminants in the Fraser River Basin to determine if the contaminants had caused or had the potential to contribute to the decline of sockeye salmon in the watershed. Their findings suggest that exposure to contaminants of concern are not the primary factor influencing the productivity or abundance of sockeye salmon. However, they did conclude that there was a possibility that exposures to contaminants of concern, including endocrine disrupters and contaminants of emerging concern, could be contributing to the decline in sockeye salmon through mechanisms such as disrupting homing/migratory instincts.

5.5 Habitat in the Fraser River Estuary

A Fraser River Estuary Management Program report (FREMP 1997) estimated that more than 800 million juvenile fish pass through the Fraser River estuary each year as they migrate out to sea. Rosenau and Angelo (1999) summarized statistics on the changes that have taken place in the estuary between 1880 and 1978. The study estimated that 70% of the original tidal lands had been altered by dredging, diking, infilling and draining, and that an estimated 50% of the actual habitat had been lost.

The following summary was provided in the report:

	Historic Areas (ha)	1978 Areas (ha)	% Reduction
Salt marsh	2,230	380	83%
Bullrush marsh	1,760	1,690	4%
Cattail/sedge marsh	1,830	1,493	18%
Wet meadows	12,400	2,604	79%
Wet meadows/willow	2,350	258	89%
Total	**20,570**	**6,425**	**69%**

These studies and others attest to the robustness of the Pacific Salmon to adapt to changing conditions. However, the trends in coho salmon escapements indicate there are limits to their ability to adapt, and increased habitat loss due to agriculture and urban development, along with poor ocean survival, have taken their toll.

5.6 Price of Salmon in the Commercial Fishery

Data on the price of salmon was gathered to determine if there was any relationship between mining activity and the price fishers received for their catch. Figure 23 shows the trends in the total tonnage of salmon caught and the total landed value paid between 1965 and 1995. The value figures were derived from the total BC commercial fishery. Note that the available data is only provided on a province wide basis and does not breakdown the data by watersheds of origin. Figure 24 provides a comparison between the landed value of per year alongside the tonnes of ore mined per year. The general trend has been an increase in the price of fish over time and at the same time the annual amount of ore mined has also increased.

5.7 Cohen Commission

In 2009 there was an unexpected low return of sockeye salmon to the Fraser River which led to the closure of the commercial fishery for sockeye salmon, the third time in as many years. As a result of these poor returns the government of Canada initiated an inquiry into the decline of sockeye salmon in the Fraser River. Mr. Justice Cohen was appointed to lead the inquiry and initiated the preparation of several technical reports to support the Inquiry's work. The findings of several reports have already been presented in this paper. As with earlier reports studying the health of salmon stocks in the Fraser River watershed (Appendix A), the technical reports prepared for the Commission have identified mining as an industry that has the potential to impact fish and fish habitat but have not found evidence to support the supposition that the mining activities are contributing to the declining salmon stocks. The Cohen Commission is expected to release its final report on or before September 30, 2012.

Technical Report number 9 (Hinch and Martins 2011) investigated the potential effect of climate change on sockeye salmon and concluded that climate change may have adversely affected survival of Fraser River sockeye salmon and may have contributed to the observed decline in abundance and productivity in recent years. They further reported that recent analyses of the potential effects of future climate change on Fraser River sockeye salmon point to reduced survival and lower productivity if the climate continues to warm.

Technical Report number 12 (Johannes *et al.* 2011) looked at the habitat conditions in the lower Fraser River and Strait of Georgia for factors that may contribute to declining sockeye numbers. Johannes et al (2011) found a potential medium to high risk that changing water quality and biological conditions could be contributing to the degradation of sockeye habitat in the Strait of Georgia. However, they also point out that relationship between these habitat changes and declining sockeye numbers between 1990 and 2009 are inferred by observation and additional research is required to substantiate these linkages.

Technical Report number 7 by English *et al.* (2011) reviewed the management of all aspects of the sockeye fishery of Fraser River stocks and also reviewed the management methods used on the Bristol Bay stocks. The report considered if management of the Fraser River sockeye fishery was a contributing factor to the decline in sockeye numbers up to 2009 and also discusses the similarities and differences in sockeye fishery management practices in the Fraser River and Bristol Bay fisheries. Several differences in approaches used to manage and assess both fisheries were identified and are described below:

- Management Structure: The Fraser River sockeye stocks and fisheries are affected by the 1985 Canada/US Pacific Salmon Treaty, which created the Fraser River Panel responsible for management of the fisheries. Representatives for the Fraser River Panel include: DFO, Washington Department of Fish and Wildlife, Alaska Department of Fish and Game (ADF&G), BC First Nations, US Treaty Indian Tribes, National Marine Fisheries Service, and representatives from the salmon processing industry and commercial fishing sectors from Canada and the US. Bristol Bay sockeye fishery management is less complex with only the Commissioner of ADF&G delegating management to four Area Management Biologist responsible for his/her specific geographic area.
- Fisheries and Stocks: On the Fraser River, the entire run is destined for a single large river and management goals are set for four run-timing groups. Furthermore, harvesting occurs anywhere from 200 km along the coast to the mouth of the Fraser and along much of the river and includes a mix of commercial gear types, sport fishing and aboriginal fisheries. For Bristol Bay, the fish return to nine river systems with 5 targeted fish districts. From this system, very few interception/mixed stock issues are created. For the Fraser River sockeye, daily harvest rarely exceeds 0.2 million fish and begins in mid July in the ocean and continues to late September in freshwater. Whereas in Bristol Bay daily harvest rates exceed 2 million fish with the fishery beginning early June for about 6 weeks. Annual harvest over the last 20 year was 5 million for the Fraser River Sockeye compared to 26 million in Bristol Bay. In Bristol Bay there has been very few seasons of little to no harvesting as compared to the Fraser River where 6 of the last 20 years have had little to no commercial harvest.
- Variability in Returns and Escapement Goals: The variability in the average annual return of sockeye salmon for the Fraser River is twice as high as for Bristol Bay. This high variability in returns and uncertainty with optimal escapement goals for the Fraser River sockeye has resulted in managers setting more complex management goals.
- Pre-season Forecasts: Both the Fraser River and Bristol Bay sockeye fisheries managers limit the use of pre-season forecasts.
- In-season Forecasts: Management of the Fraser River fishery is based on in-season forecasts whereas Bristol Bay managers rely more on the daily escapement counts and day-to-day movement of fish in each district.
- In-season and Post-season Escapement Enumeration: For Bristol Bay hourly tower counts provide accurate estimates of the escapement for 8 of the 9 rivers systems, whereas for the Fraser River, hydroacoustic equipment is used to monitor escapement as fish pass the station located in the lower Fraser River near the town of Mission. Escapement estimates are much less reliable in the Fraser River.
- Abundance Estimates: Fraser River abundance estimates are more difficult to estimate and are not completed until the following fishing season due to longer duration, later in the year run, longer freshwater migration and the need for spawning ground estimates. Bristol Bay managers can estimate abundance as early as September in the same year.

The Bristol Bay sockeye fishery is considered a biological success (English *at al.* 2011) in part because the management of the fishery is less complex. The various stocks are more discreet spatially and temporally than the Fraser River stocks, the fishery takes place in a relatively small area near the mouth of the major rivers and fewer jurisdictions are involved.

6. Conclusions

Salmon of the Fraser River have increased in abundance from the 1950s and 1960s through to the mid to late 1990s, while at the same time the production of precious and base metal mines has also significantly increased. On a watershed level, the evidence does not indicate that mining activities have effected overall salmon production. However, many reports do indicate that salmon populations need special attention, such as the interior Fraser coho and the Sakinaw and Cultus Lake sockeye populations in the lower Fraser Watershed that have experienced significant declines in recent years. The consensus is that wild salmon populations of the Fraser River are at risk from factors such as:

- Habitat degradation related to land use activities such as forestry, agriculture and urban development;
- Water quality impairment, which appears to be primarily related to urban effluent discharge, pulp mill discharge, including very subtle changes in water quality through the introduction of chemicals that can disrupt hormonal balances which in turn could affect salmon migration patterns;
- Climate change and other factors resulting in changes in productivity in the marine environment and changes in water temperature in the freshwater environment, both of which can have significant effects on survival; and
- Commercial and non-commercial harvest.

Despite the fact that mining projects have been identified as contributing to degraded water quality or impacting fish from accidental spills, and alterations to fish habitat, findings in the literature do not identify mining as a contributing factor affecting salmon stocks in the Fraser River Basin.

This review also documented that the price paid to commercial fishermen steadily increased through the early 1990s at the same time as the level of mining activity, measured in tonnes of ore mined, increased.

The Fraser River watershed has experienced considerable development over the past 50 years. Mining has been an important contributor to the economy within the Fraser Basin but there was no empirical evidence to suggest that mining has a significant role in recent declines in salmon populations. Studies such as those completed for the Cohen Commission and others (Appendix A), typically place greater emphasis on wider spread developments such as forestry and urban growth and associated infrastructure (i.e. road development, effluent discharge, etc.), and effects of the Mountain Pine Beetle as possible contributors to declining salmon numbers. The crash of sockeye numbers in 2007, 2008 and 2009, precipitated review efforts by organization such as the Pacific Salmon Commission and eventually resulted in the formation of the Cohen Commission. The technical reports prepared for the Cohen Commission and work by other researchers (i.e. Peterman 2010) have increased attention paid to smolt survival in nearshore marine habitats (i.e. Georgia Strait) and the offshore marine environment as areas where environmental changes may be contributing to the decline of salmon stocks. However, there has been little research effort focused on understanding what is occurring in those habitats. Based on this review of the empirical evidence, mining activity in the Fraser River watershed over the last 50 years has not had a negative effect on salmon populations and the commercial salmon fishery. There is no evidence of watershed wide effects from mining on salmon habitat. The evidence also shows no relationship between salmon price and mining activity.

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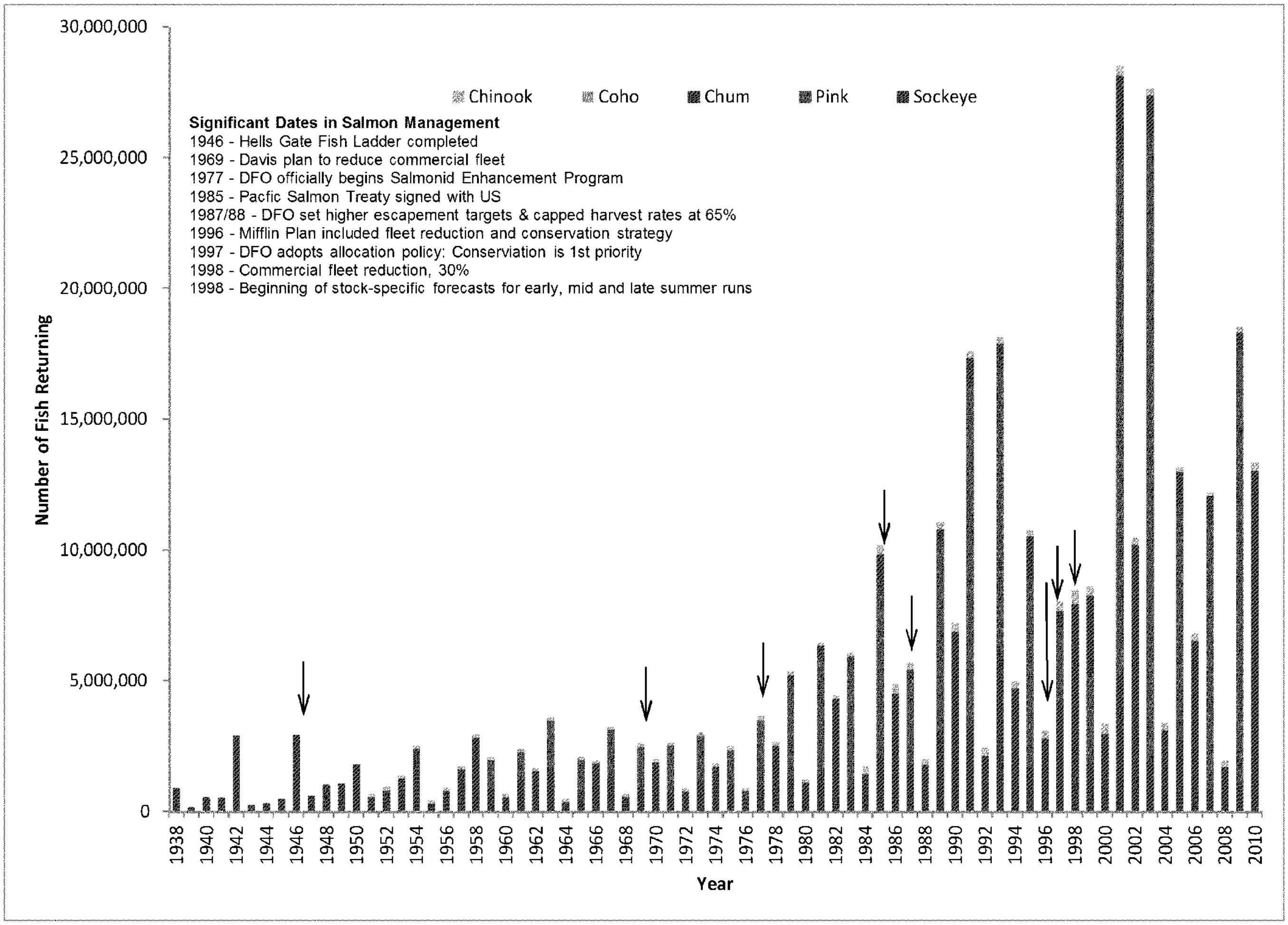
Figures

Figure 1. Total Fraser River Salmon Escapement



**Note: 2008-2010 are only estimates and not all species has data available yet – numbers are subject to change.*

Figure 2. Total Fraser Watershed Sockeye Salmon Escapement

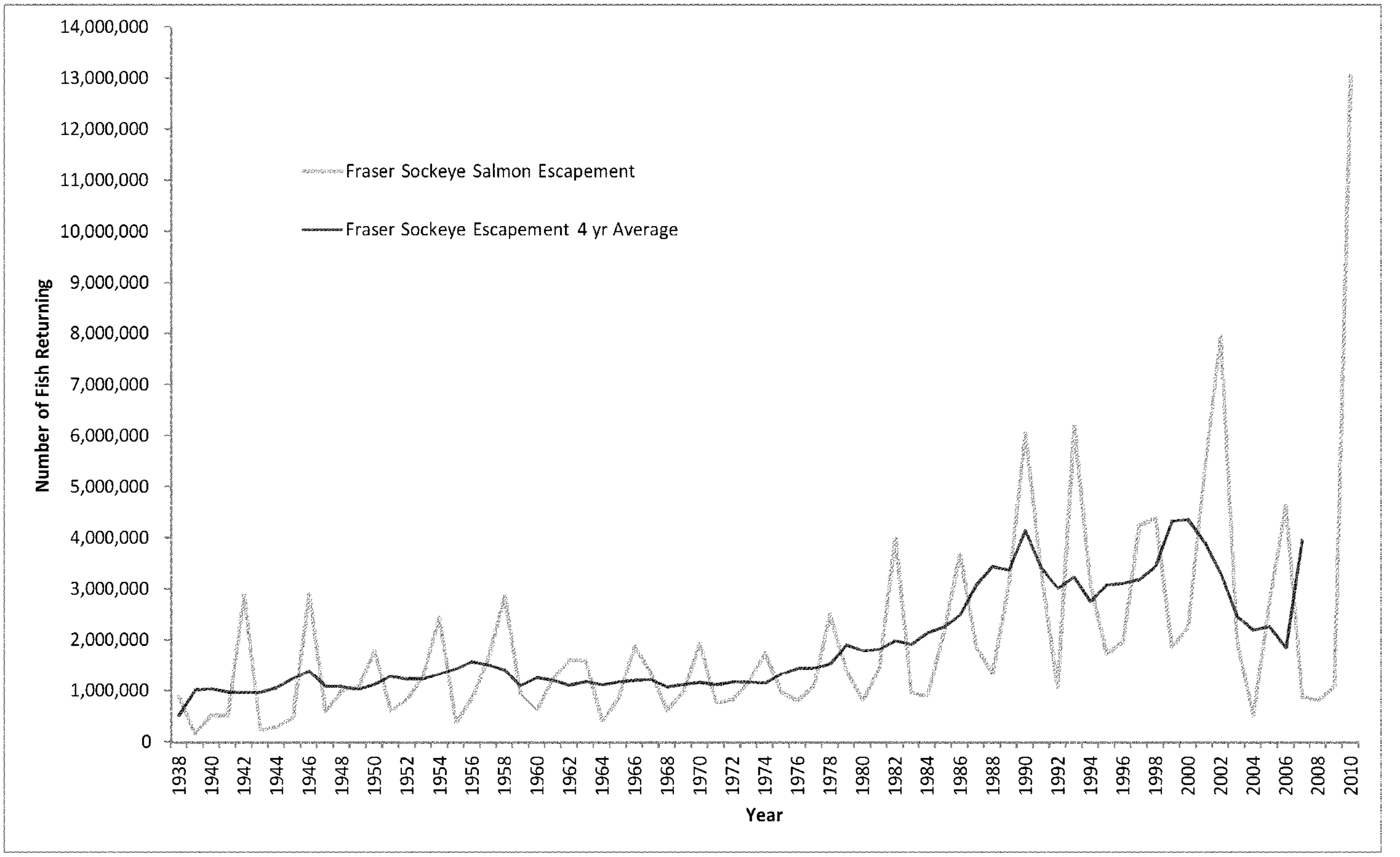


Figure 3. Total Fraser Watershed Chinook Salmon Escapement

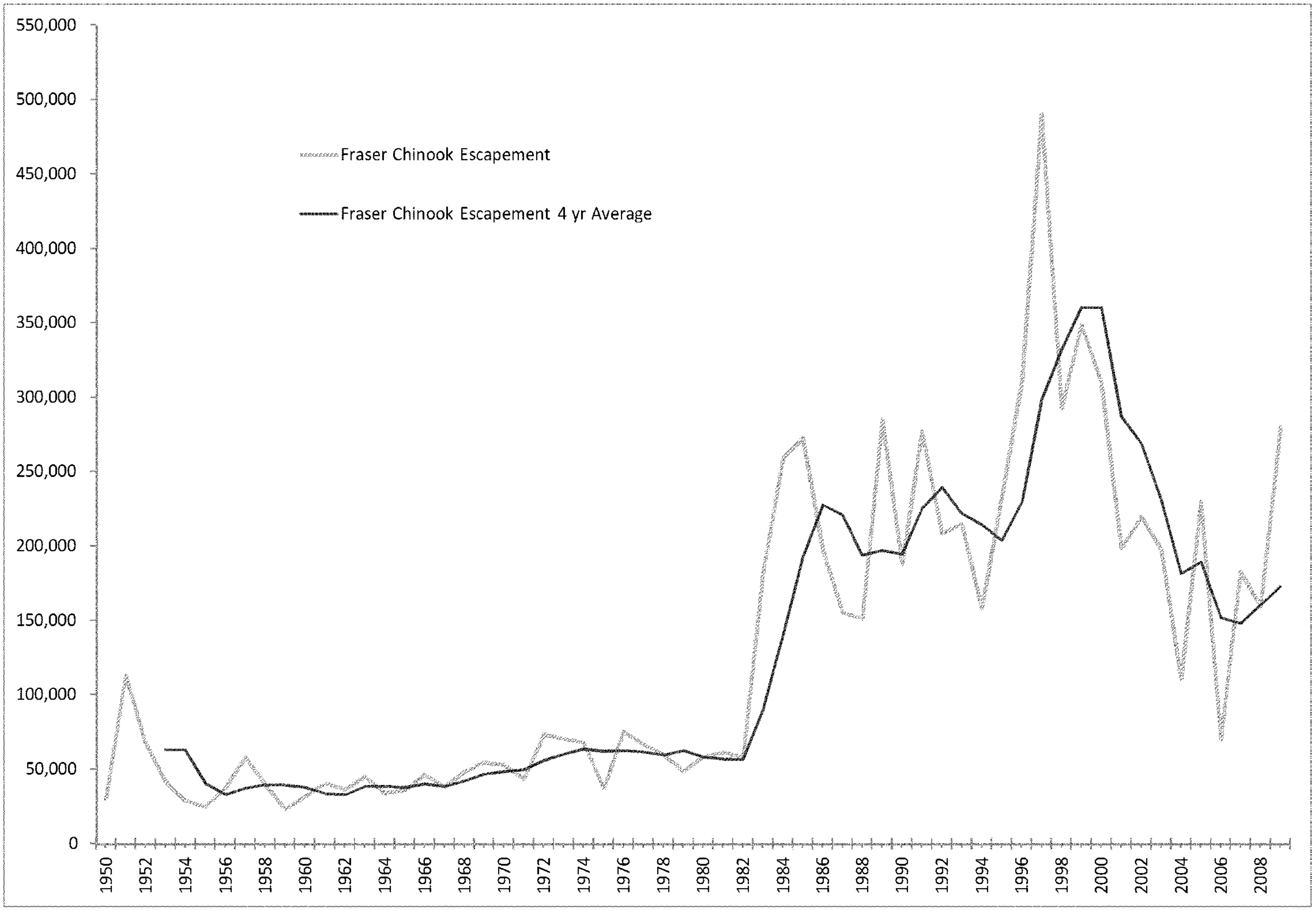


Figure 4. Total Fraser Watershed Chum Salmon Escapement

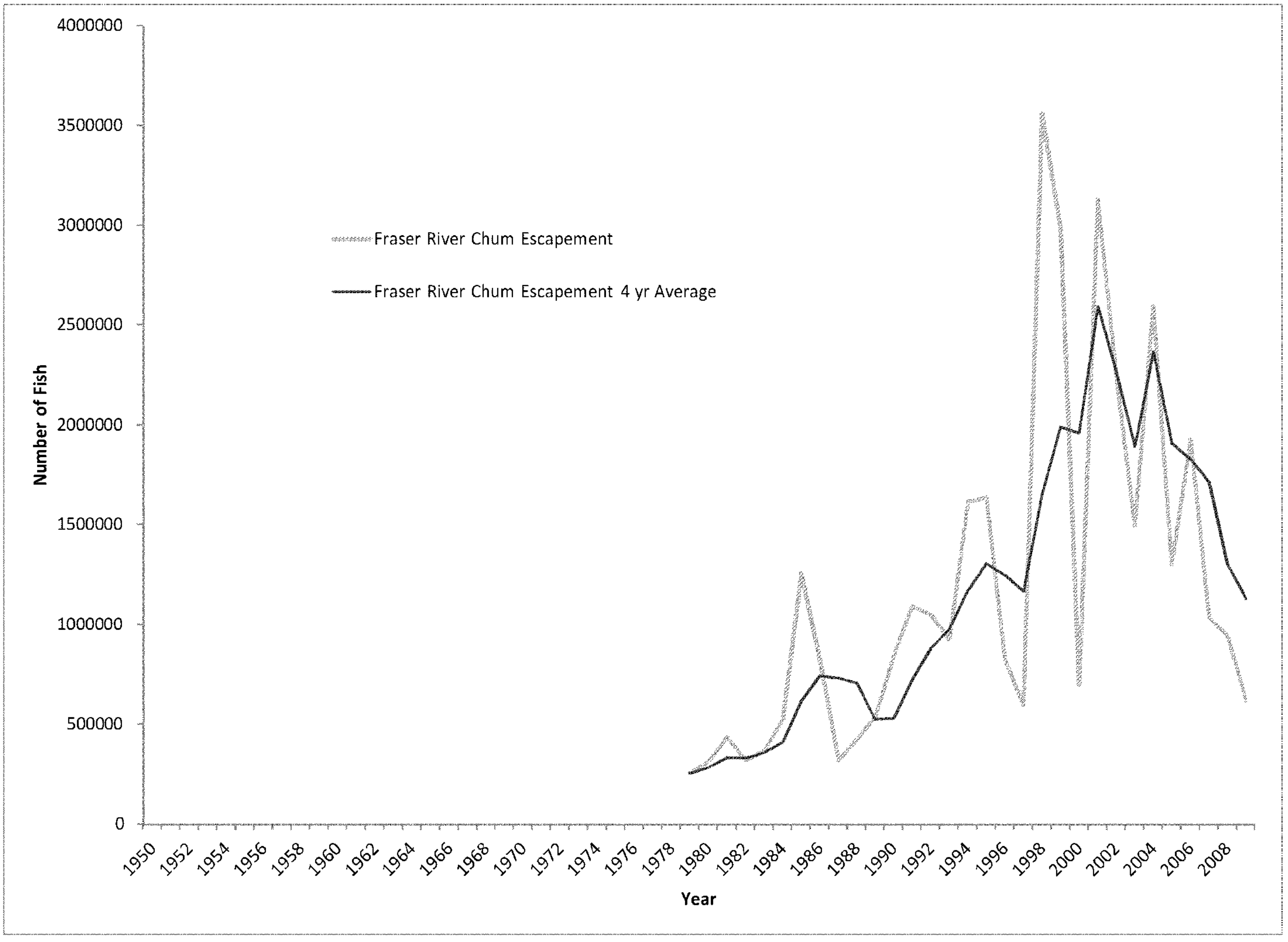


Figure 5. Fraser River Pink Escapement

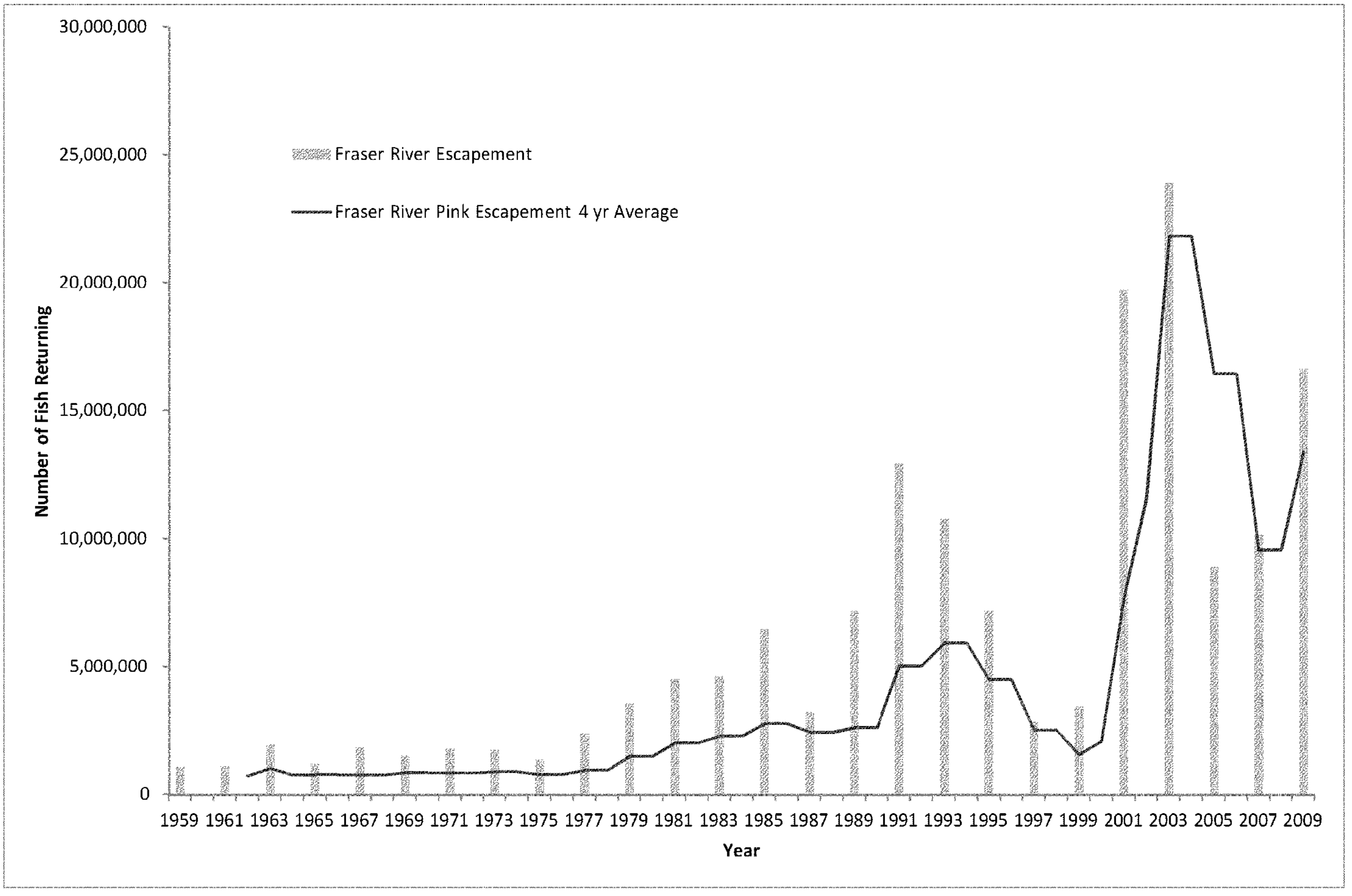


Figure 6. Fraser Coho Salmon Escapement

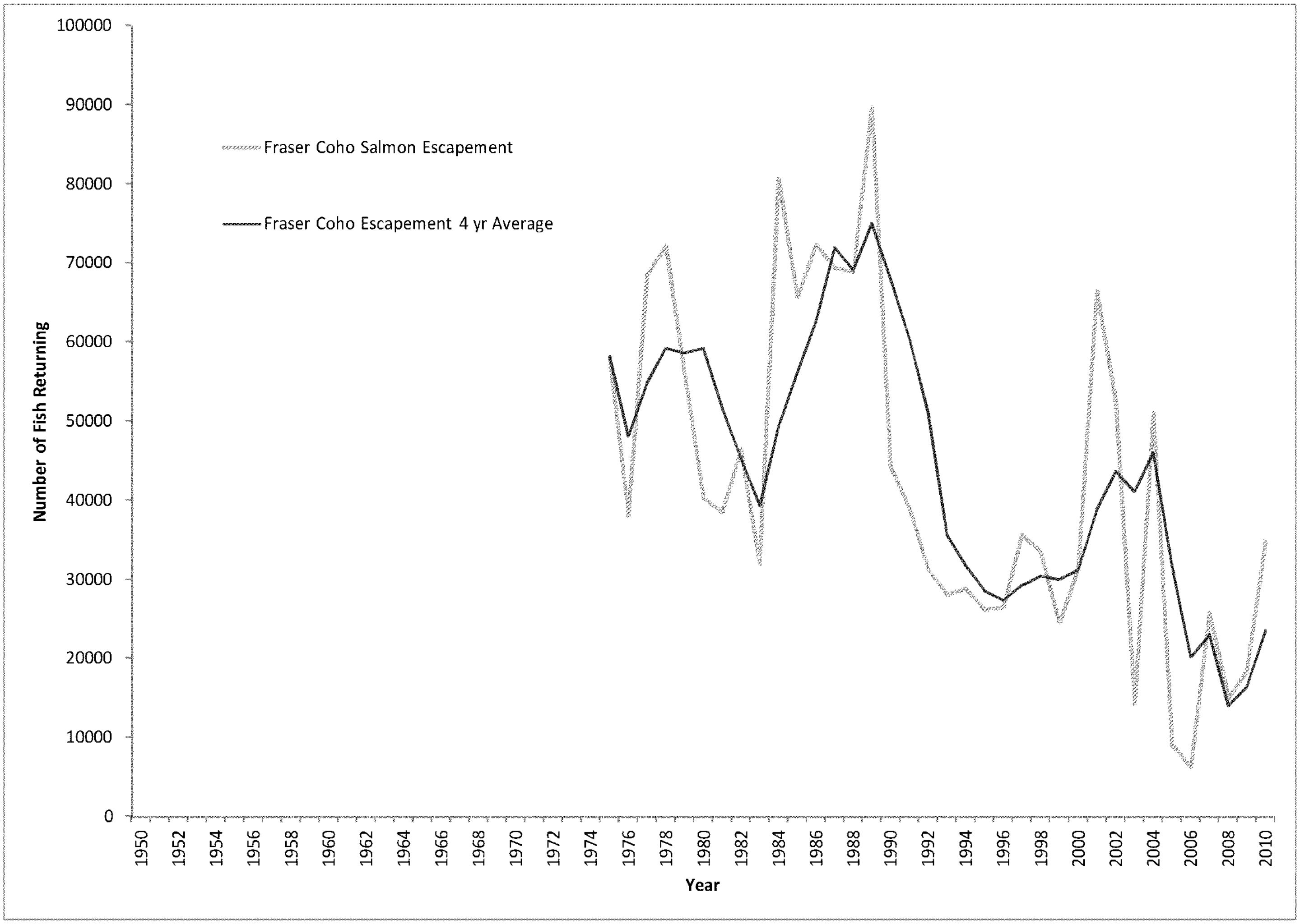


Figure 7. Nechako Salmon Escapement

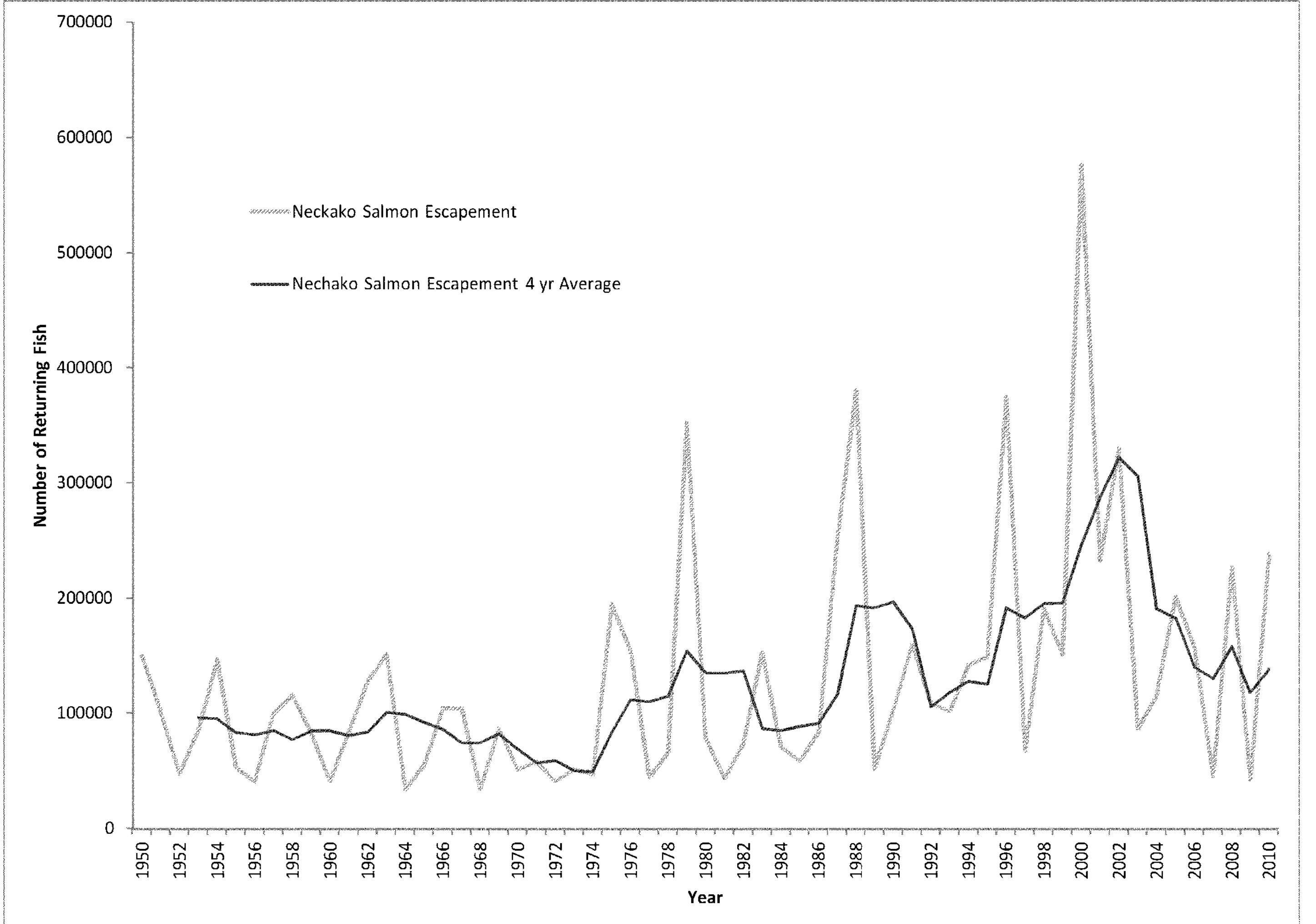


Figure 8. Nechako Watershed Sockeye Escapement

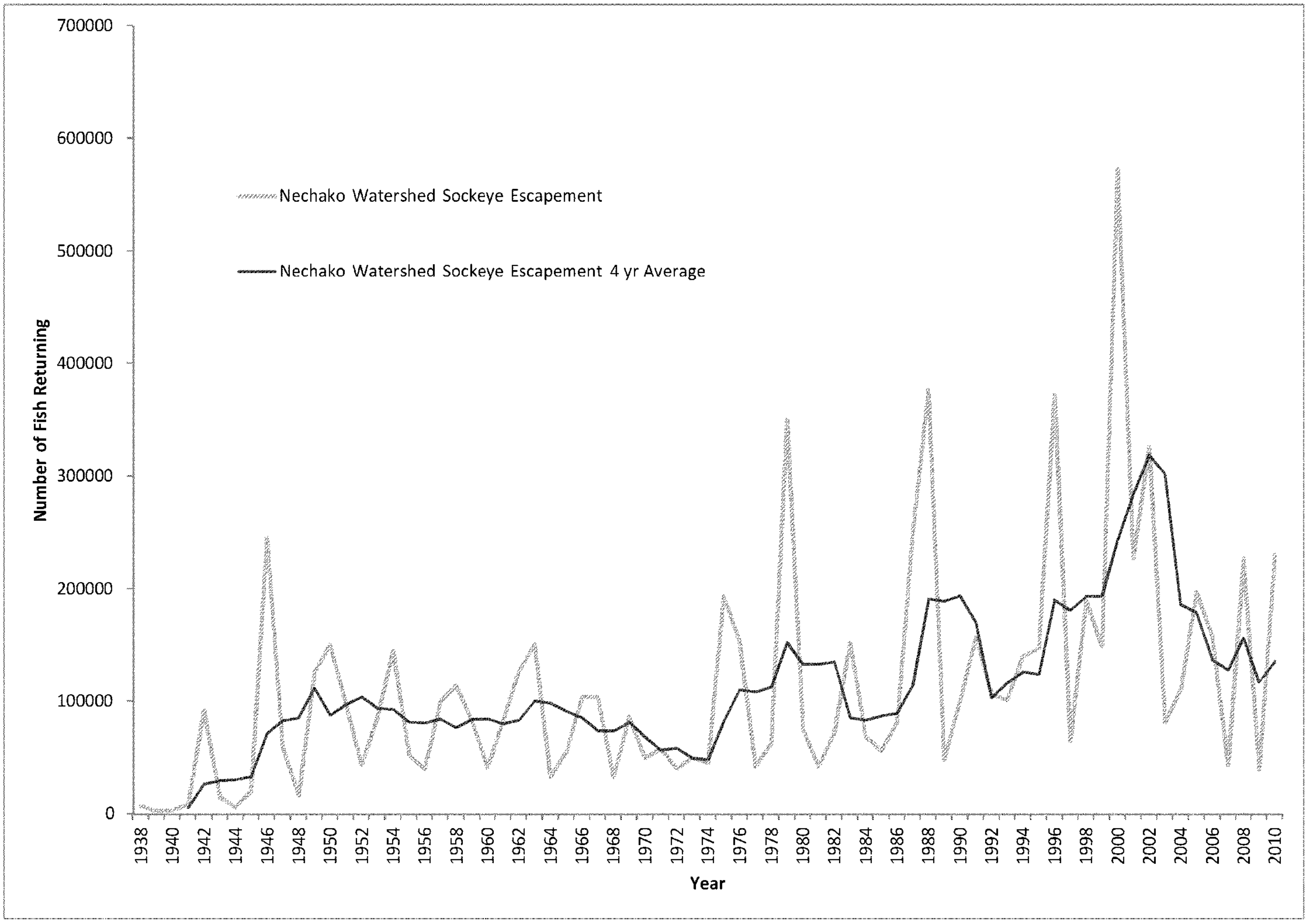


Figure 9. Nechako Watershed Chinook Escapement

Figure 10. Stuart Salmon Escapement

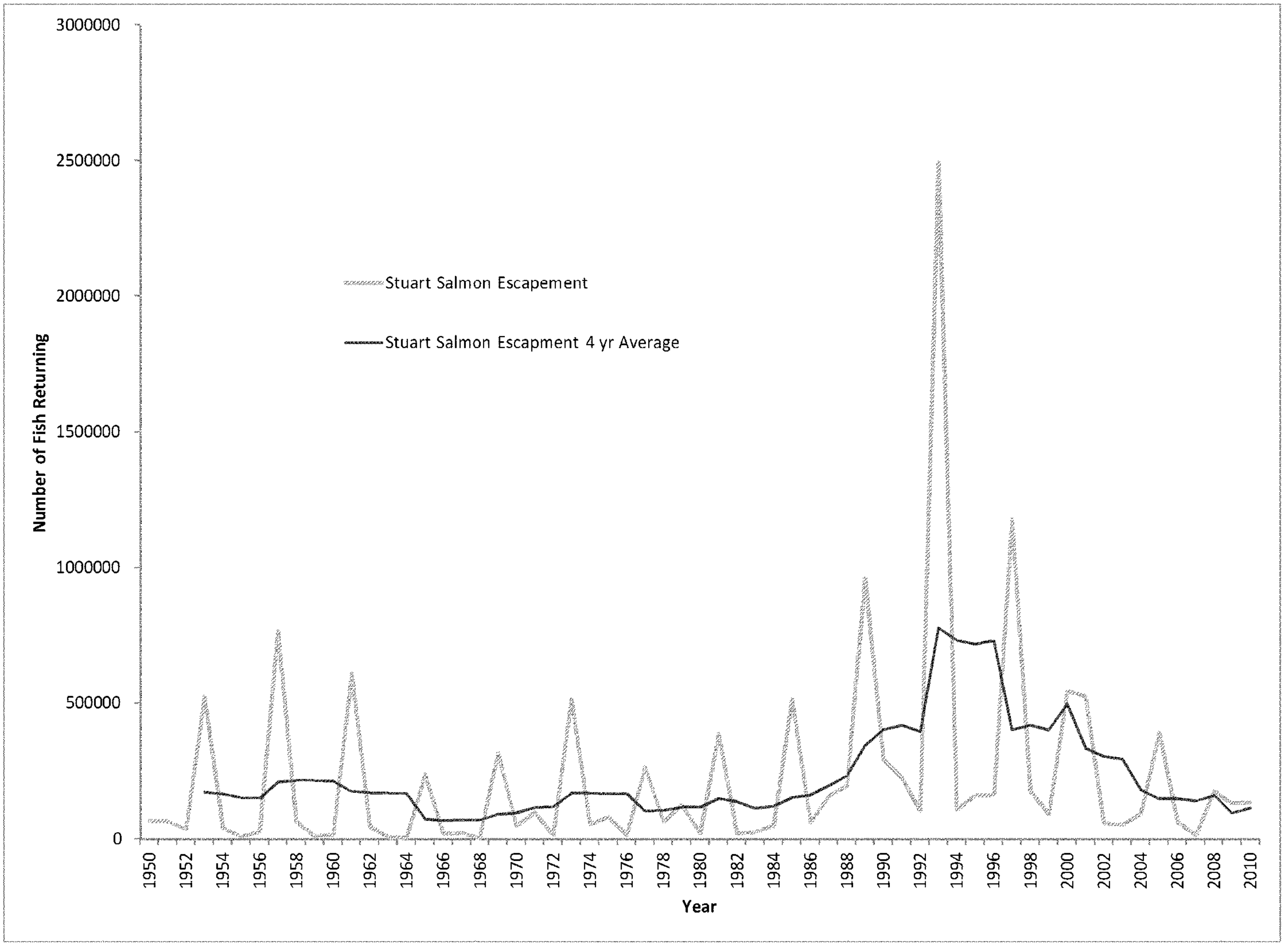


Figure 11. Stuart Watershed Sockeye Escapement

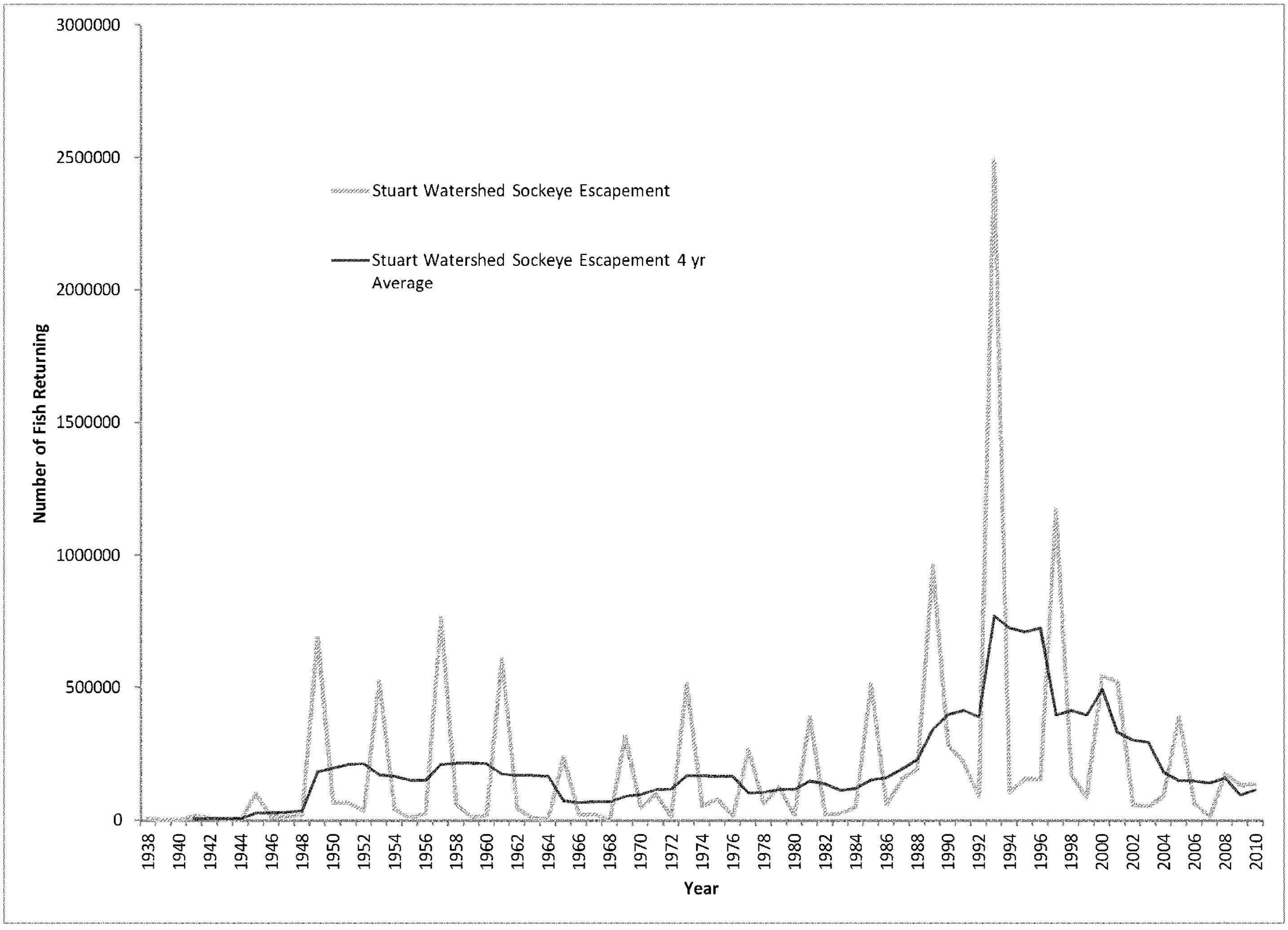


Figure 12. Stuart Watershed Chinook Escapement

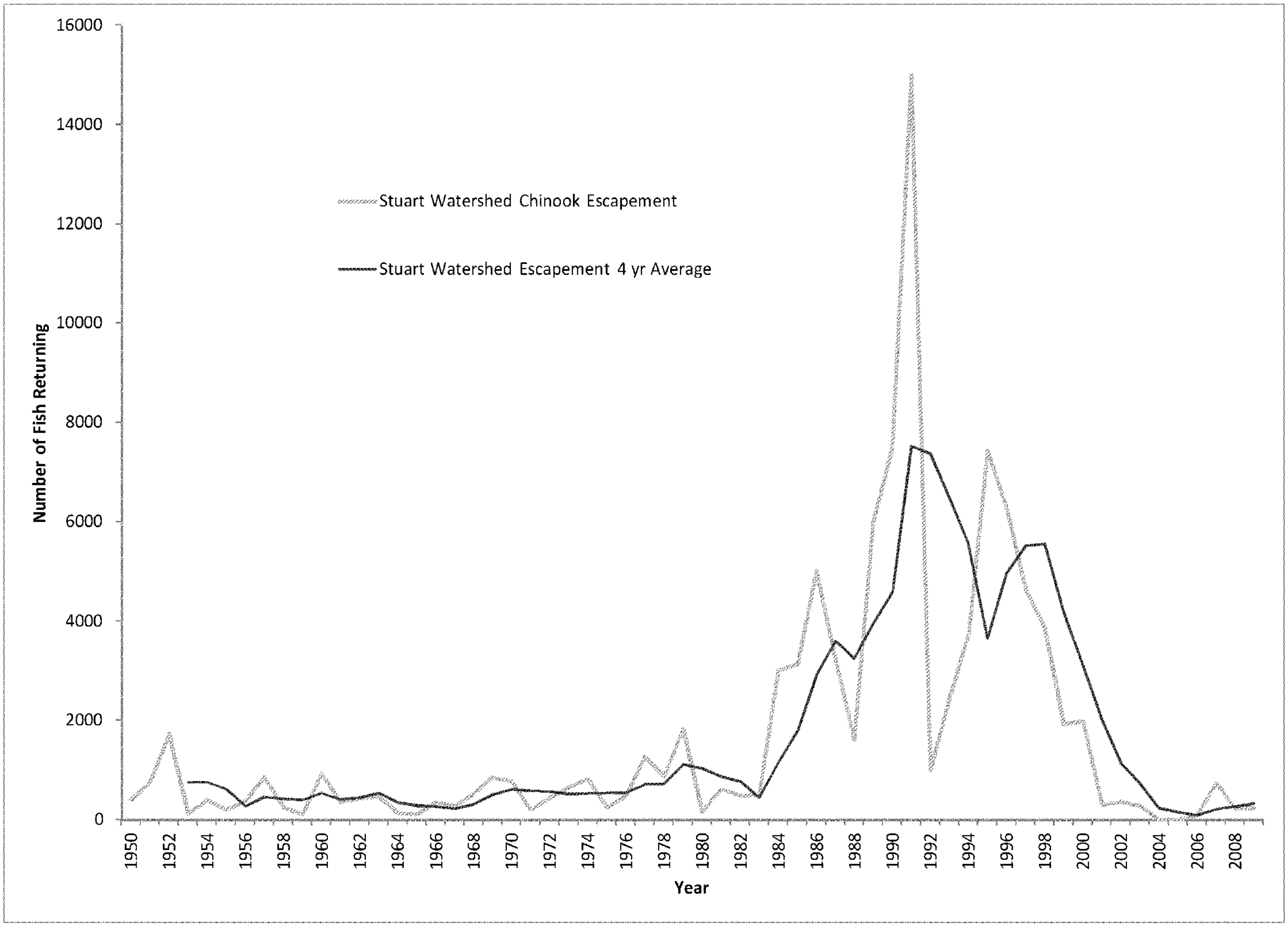


Figure 13. Quesnel Salmon Escapement

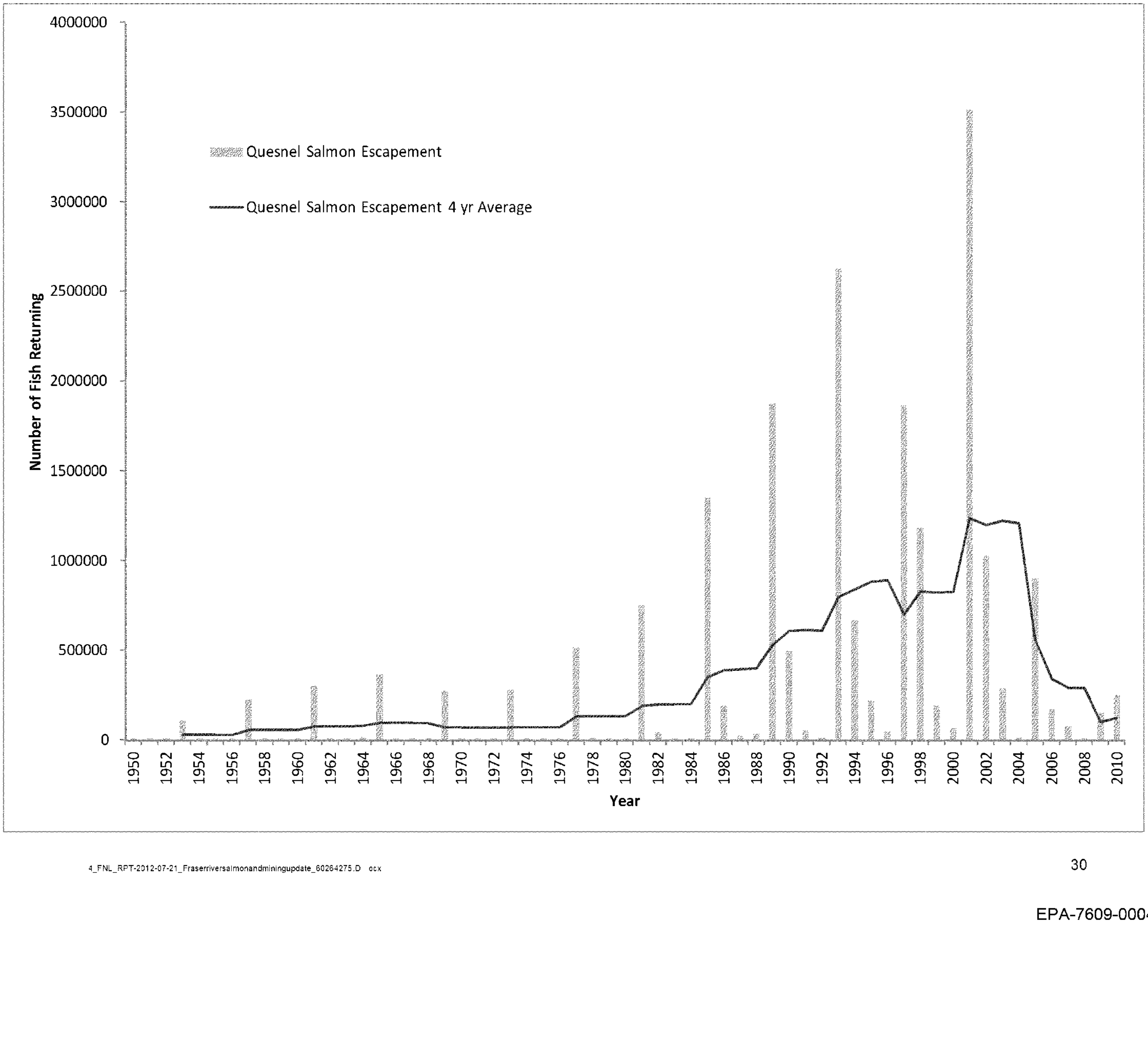


Figure 14. Quesnel Sockeye Escapement

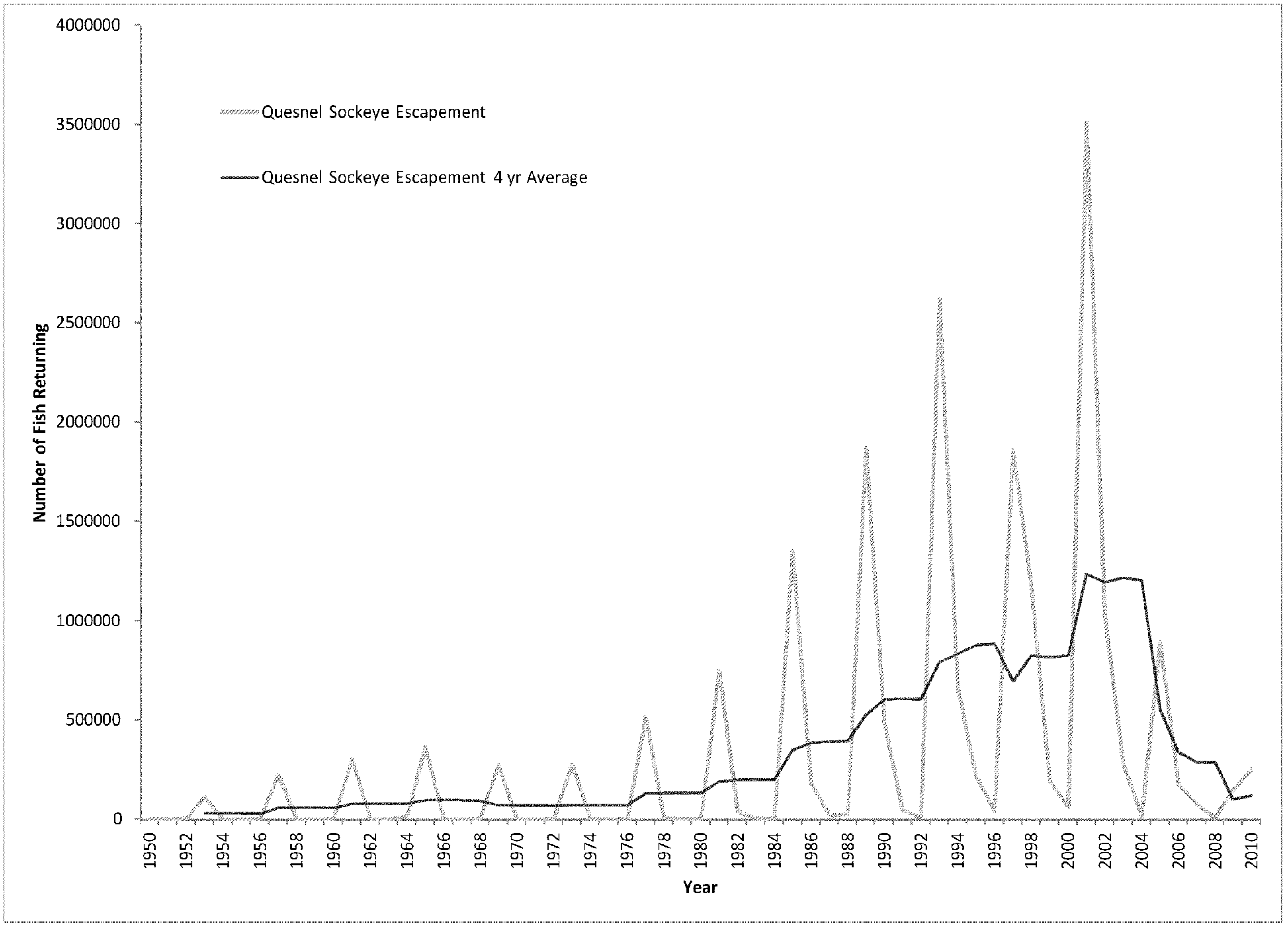


Figure 15. Quesnel Watershed Chinook Escapement

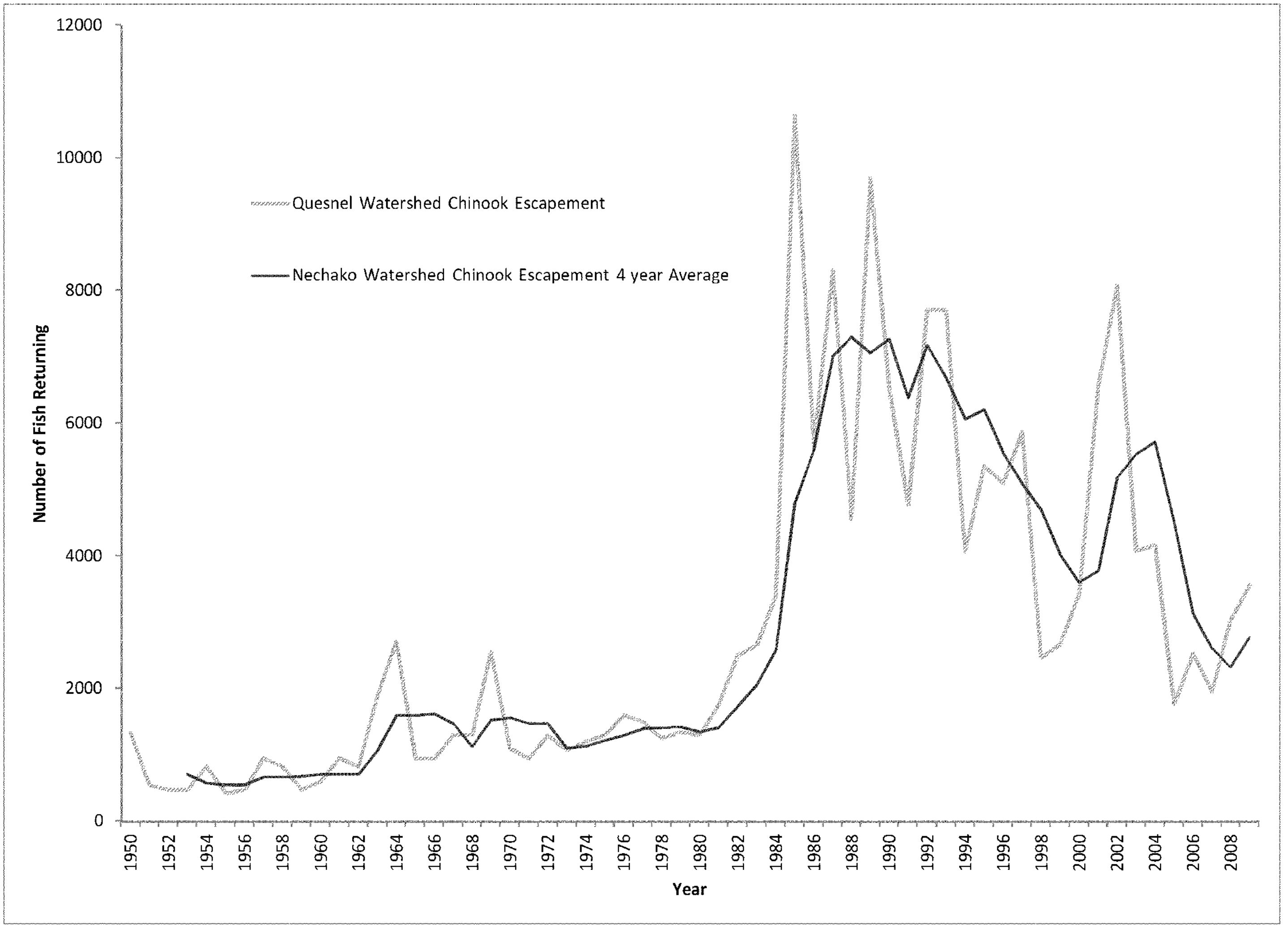


Figure 16. Thompson Salmon Escapement

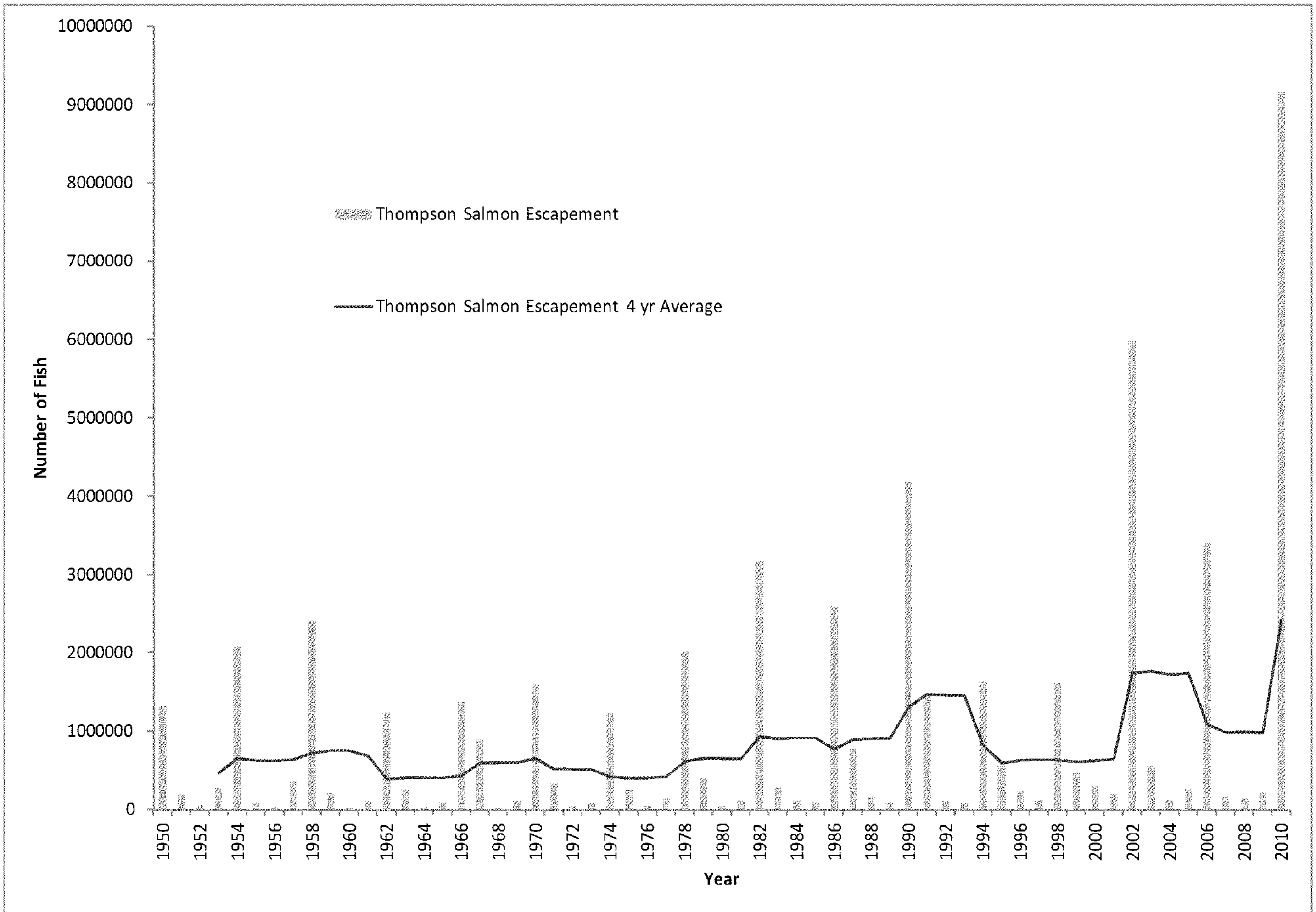


Figure 17. Thompson Watershed Sockeye Escapement

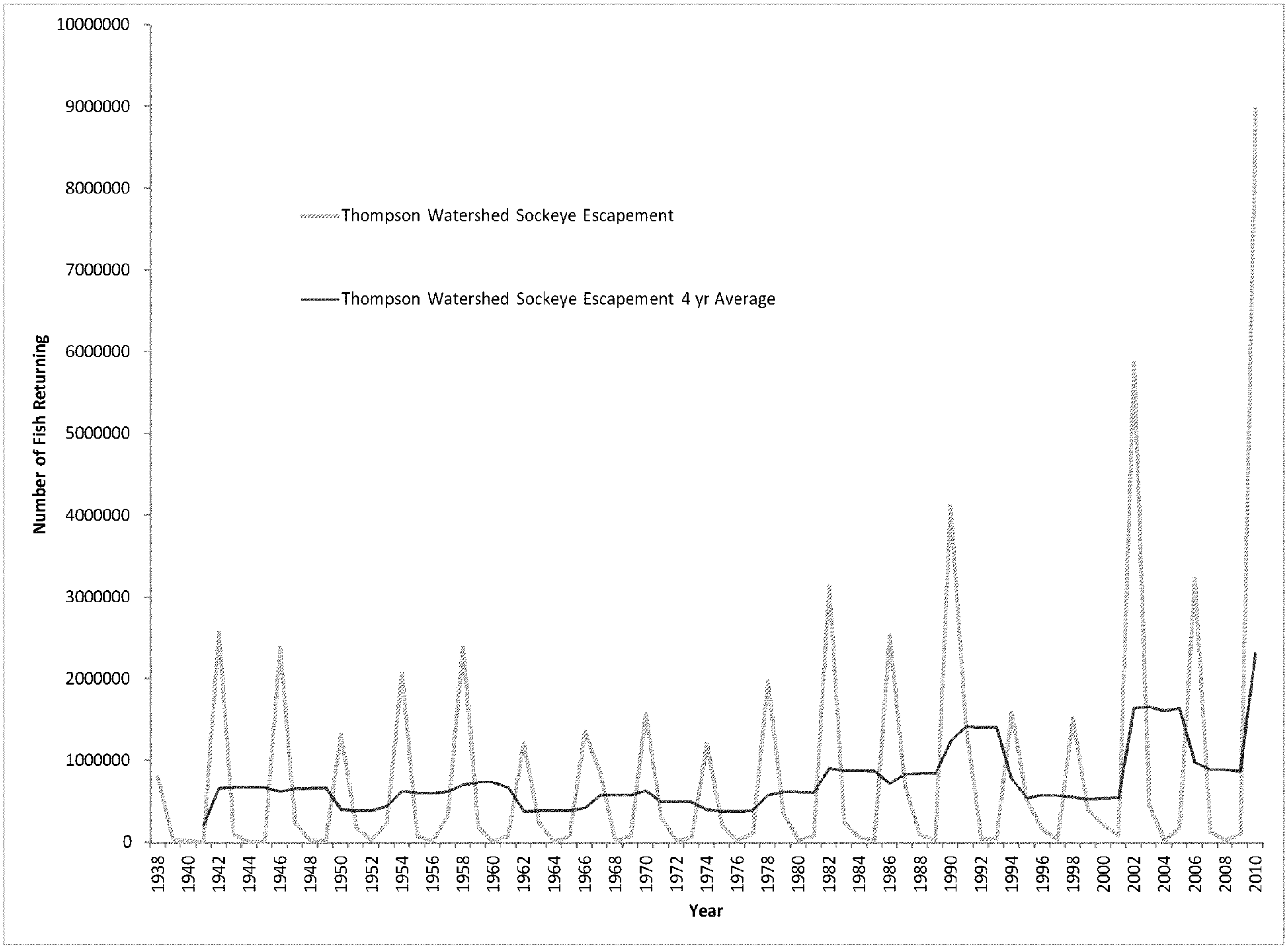


Figure 18. Thompson Watershed Chinook Escapement

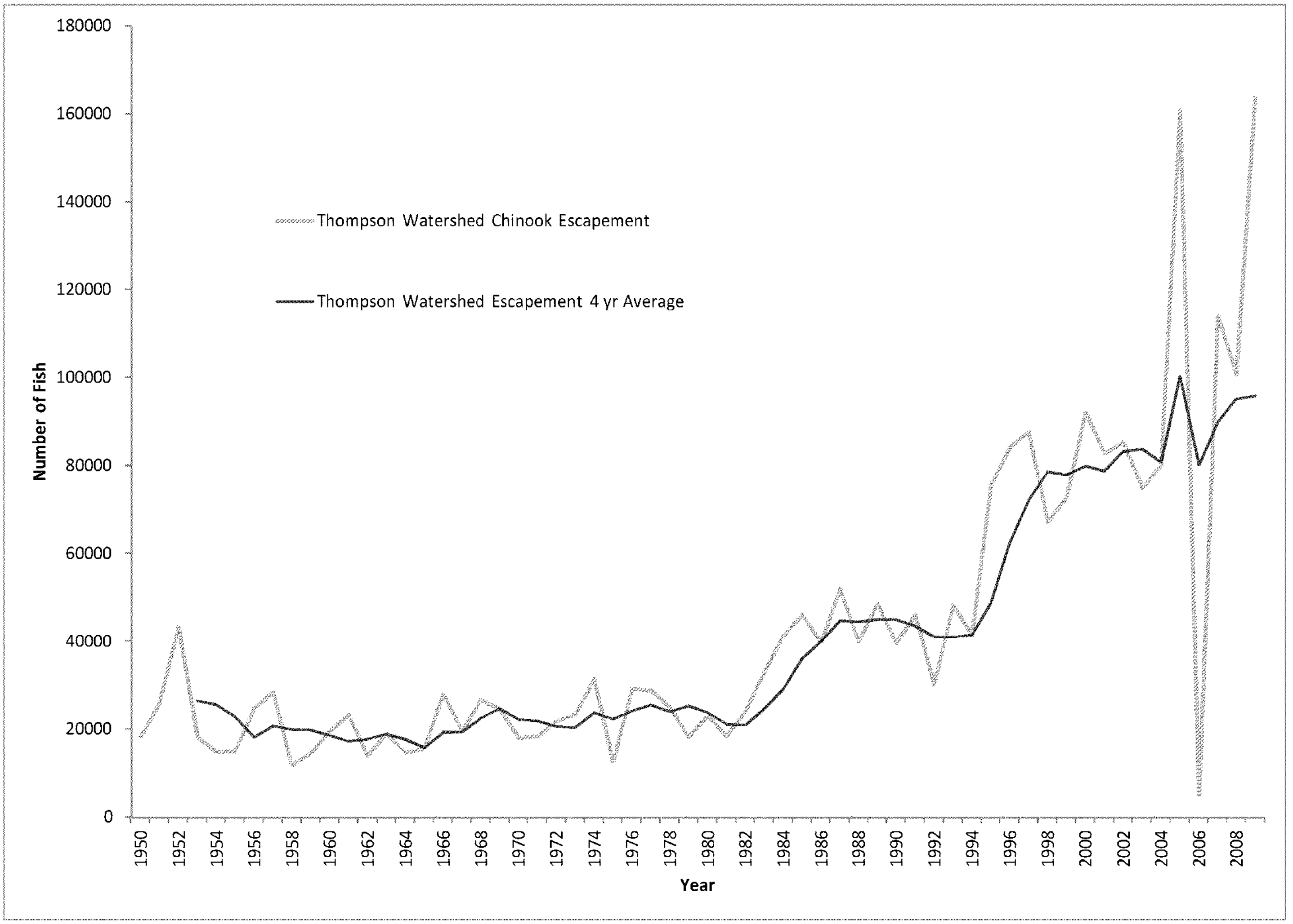


Figure 19. Thompson Coho Escapement

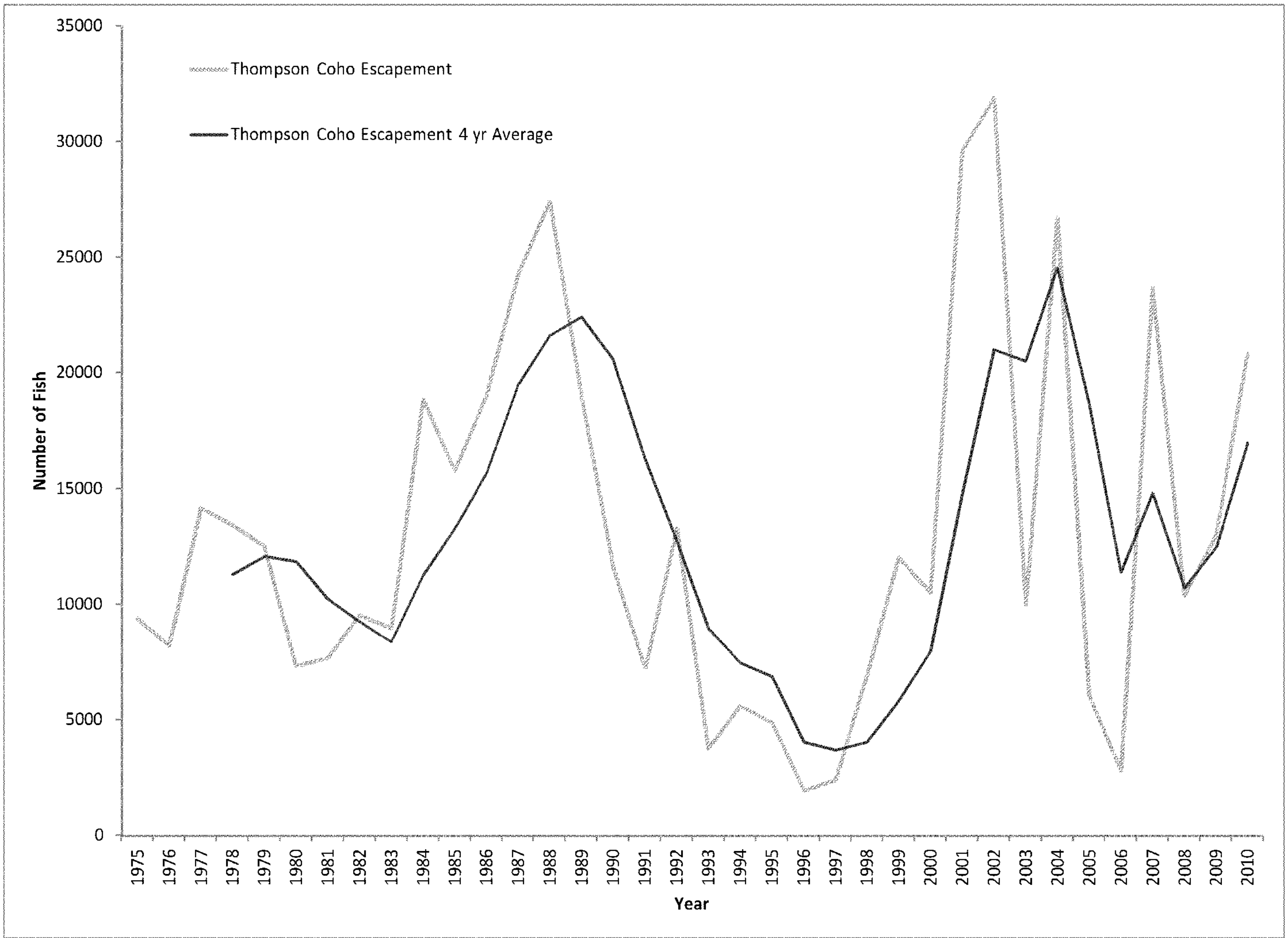


Figure 20. Fraser River Sockeye Returns (Escapement + Catch)

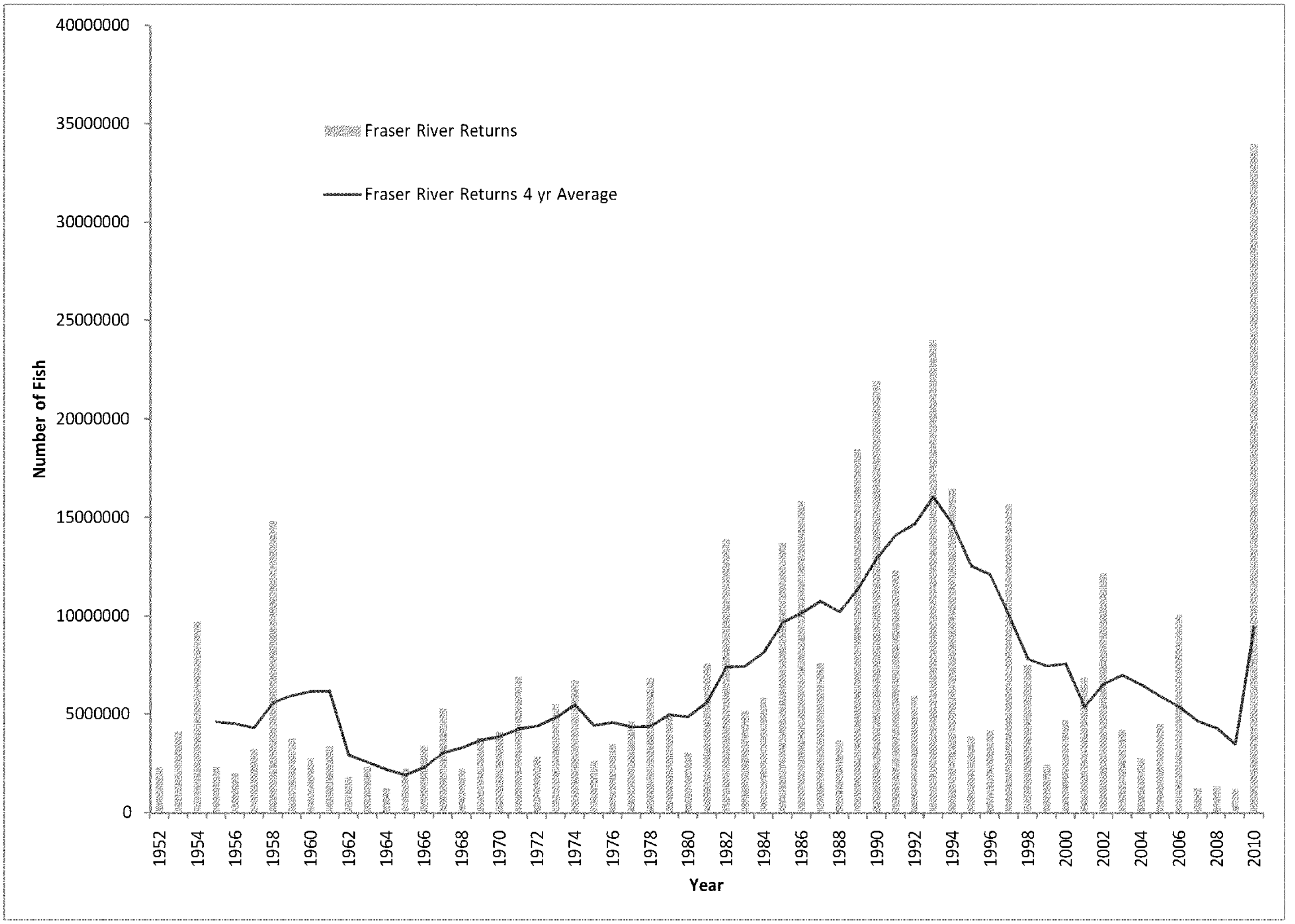


Figure 21. Fraser River Sockeye Exploitation vs Escapement

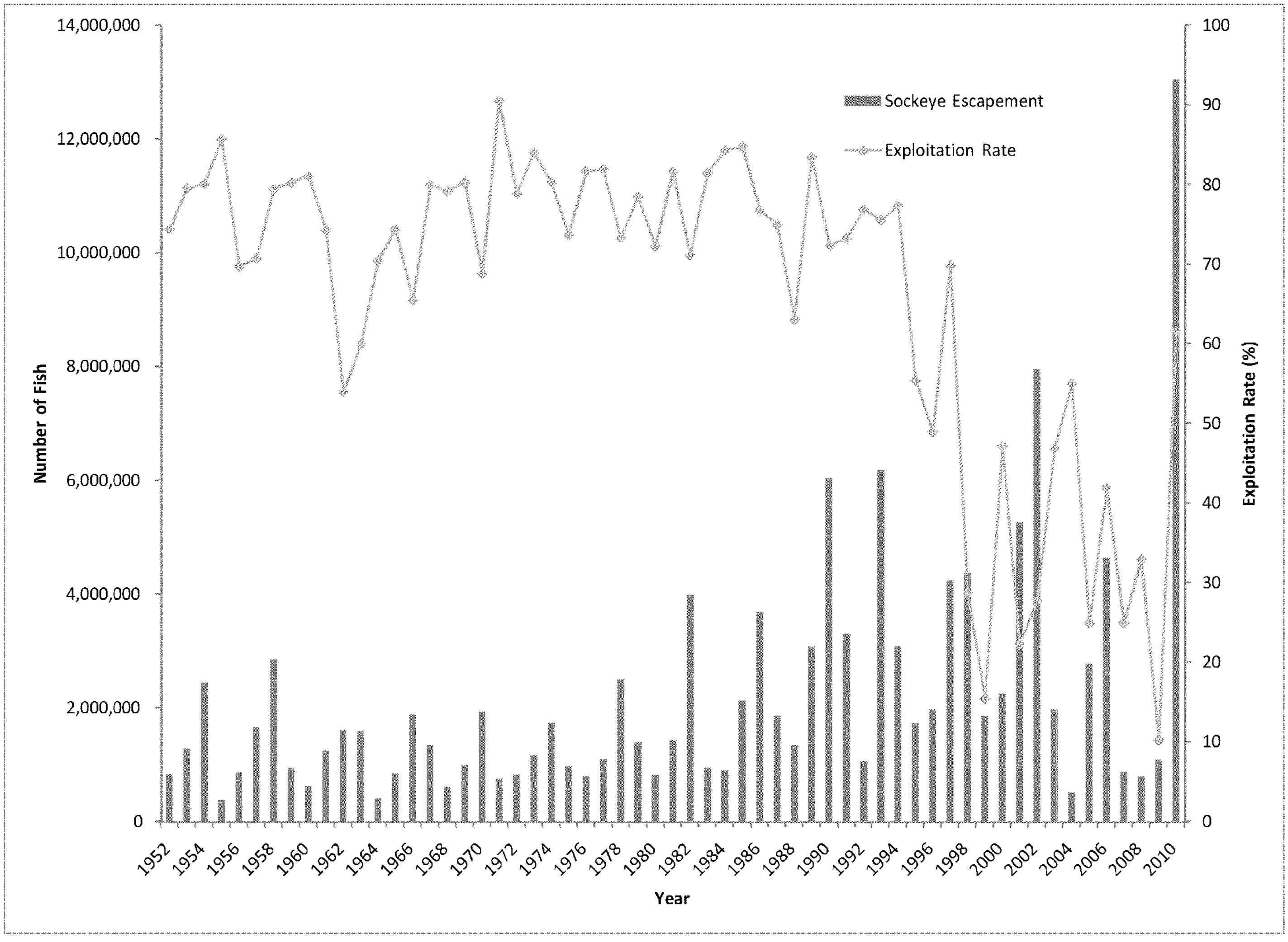


Figure 22. Mined Metals Tonnage Versus Salmon Escapement in Fraser Watershed

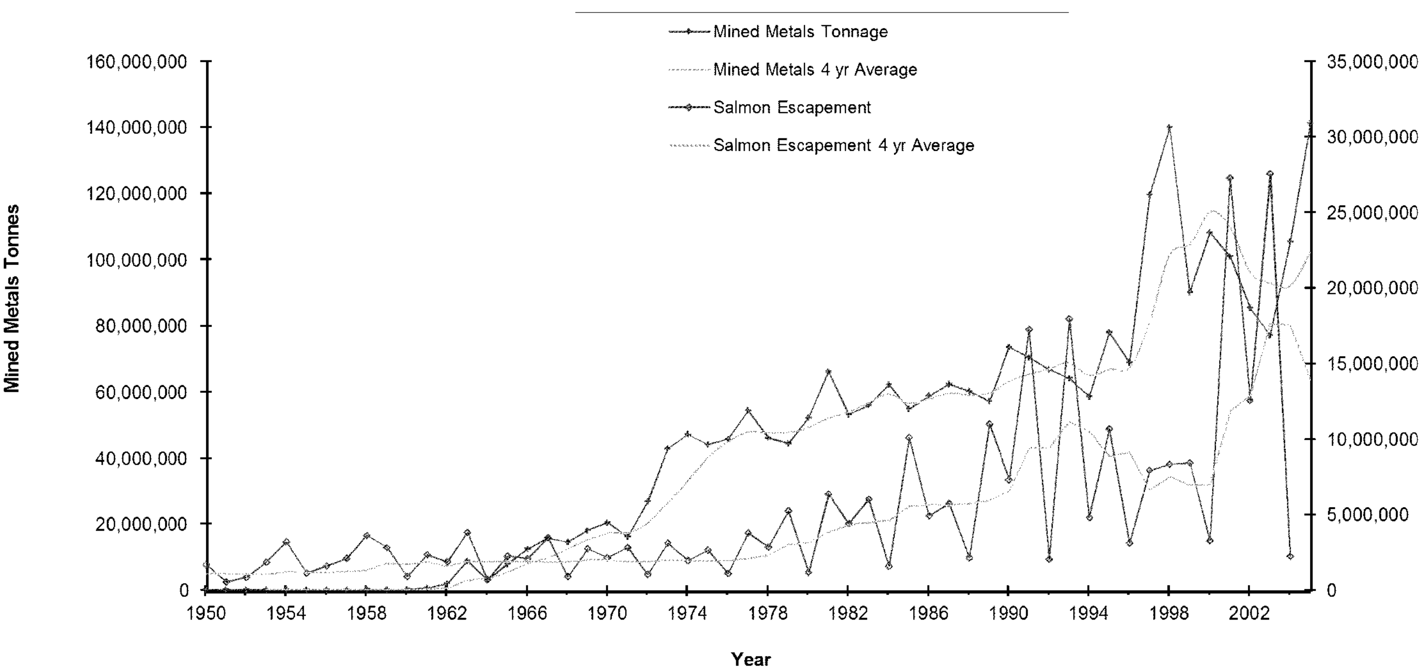


Figure 23. Salmon Landed Weight and Value in BC

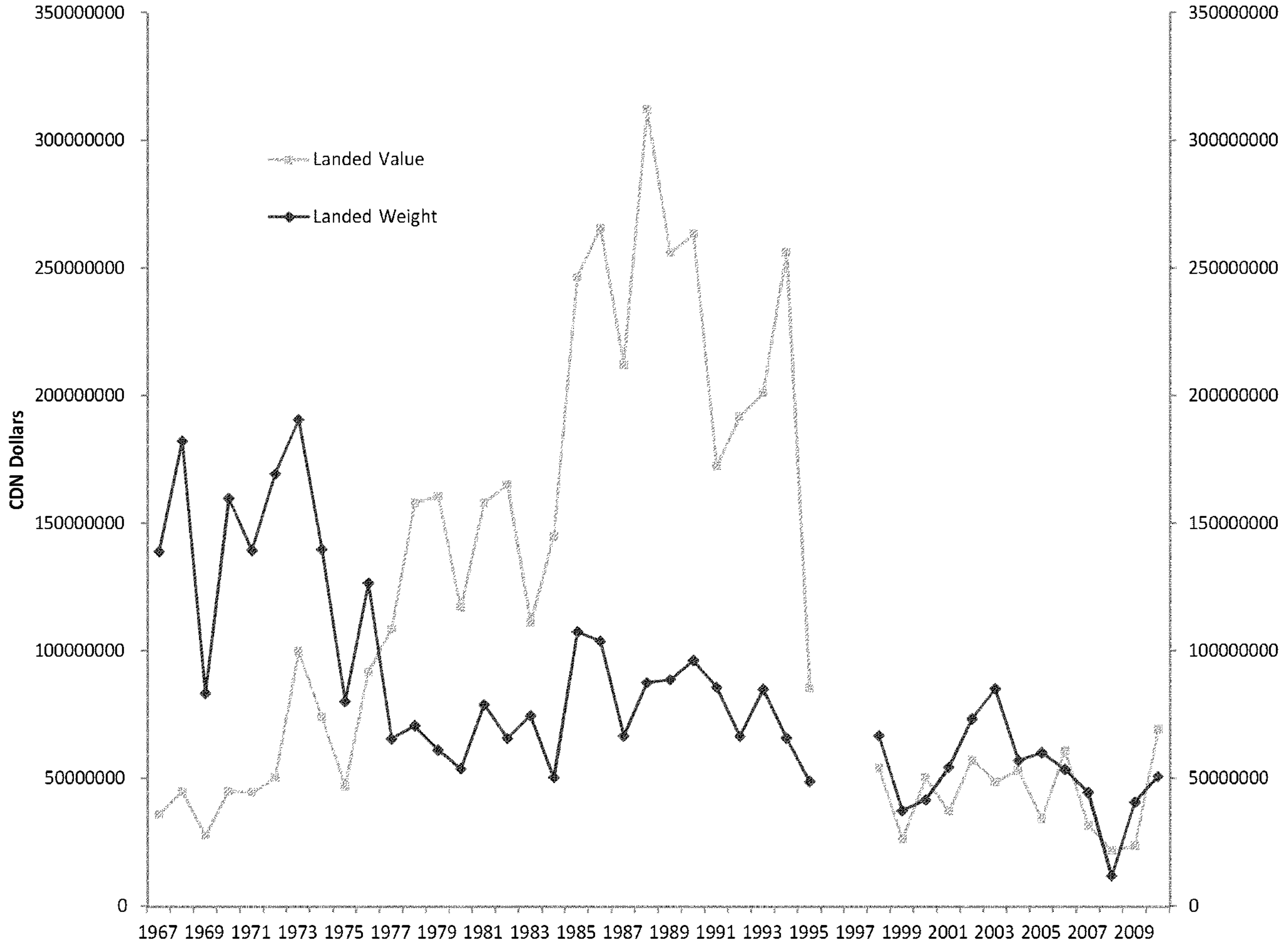
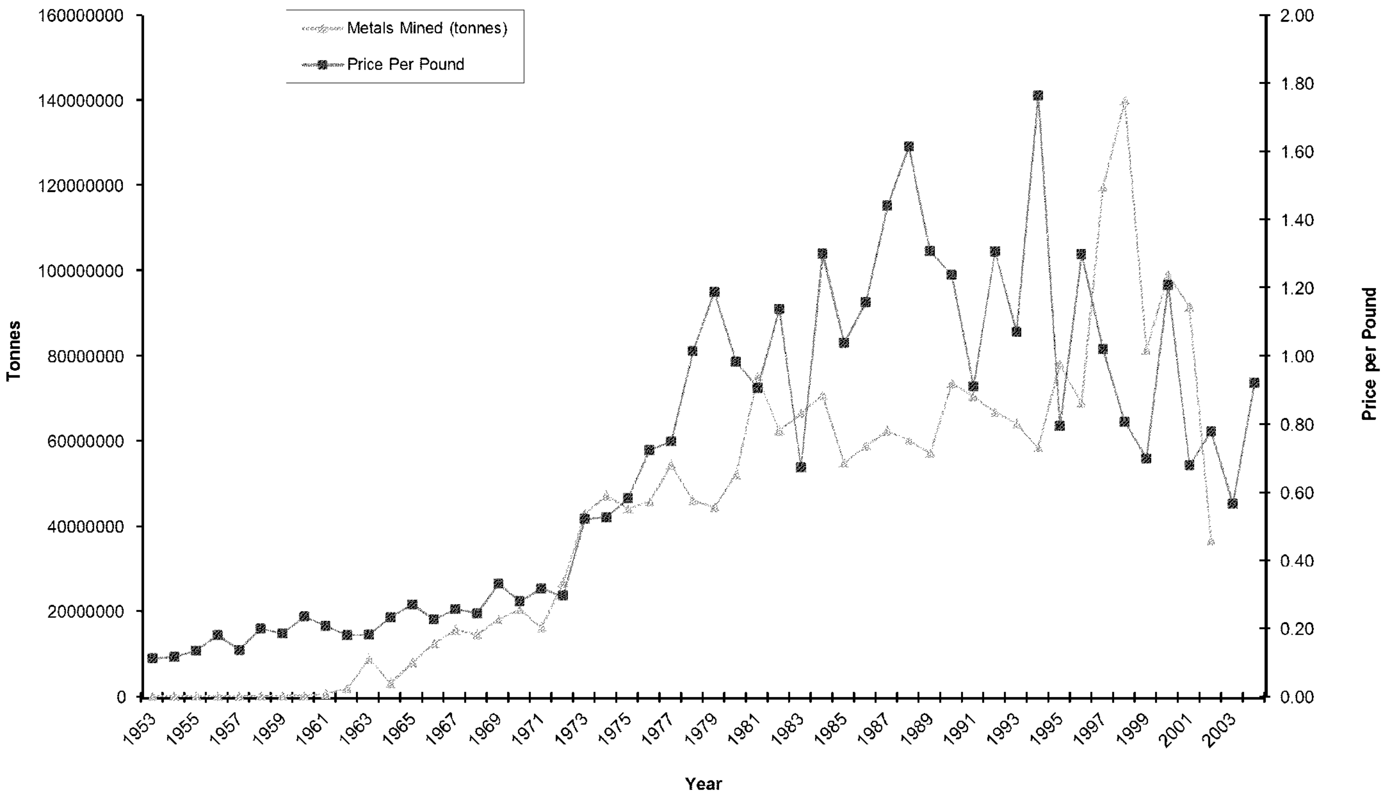


Figure 24. Metal Production and Salmon Price



Appendix A

Fraser River Salmon and Mining - Report Review Summary

	A	B	C	D	E	F	G	H	I	J	K	L
1	**Topic-General**	**Topic-Specific**	**Report Title**	**Source**	**Year**	**Citation**	**Mention Mining?**	**Summary**	**Data Quality**	**Location of Article**	**Digital Version Available?**	**Reviewer (initial)**
2	**Physical**	Land area	Health of the Fraser River Aquatic Ecosystem, Vol. II .		1998	Health of the Fraser River Aquatic Ecosystem, Vol. II .A Synthesis of Research Conducted under the Fraser River Action Plan. DOE (Environment Canada) FRAP 1998-11.		234,000 sq km		http://www.rem.sfu.ca/FRAP/S_cov.pdf.		Provided by NDM
3	**Physical**	Water	Health of the Fraser River Aquatic Ecosystem, Vol. II .		1998	Health of the Fraser River Aquatic Ecosystem, Vol. II .A Synthesis of Research Conducted under the Fraser River Action Plan. DOE (Environment Canada) FRAP 1998-11.		1,375 km of river length, 13 major tributaries		http://www.rem.sfu.ca/FRAP/S_cov.pdf.		Provided by NDM
4	**Physical**	Discharge (mean annual)	Health of the Fraser River Aquatic Ecosystem, Vol. II .		1998	Health of the Fraser River Aquatic Ecosystem, Vol. II .A Synthesis of Research Conducted under the Fraser River Action Plan. DOE (Environment Canada) FRAP 1998-11.		3,600 m3/s		http://www.rem.sfu.ca/FRAP/S_cov.pdf.		Provided by NDM
5	**Physical**	Parkland	Health of the Fraser River Aquatic Ecosystem, Vol. II .	FRAP	1998	Health of the Fraser River Aquatic Ecosystem, Vol. II .A Synthesis of Research Conducted under the Fraser River Action Plan. DOE (Environment Canada) FRAP 1998-11.		6% of land area is provincial parkland (1991)		http://www.rem.sfu.ca/FRAP/S_cov.pdf.		Provided by NDM
6	**Human Settlement**	Population base	Fraser Basin Statistical Profile	BC Stats	2004	Fraser Basin Statistical Profile, Prepared by BC Stats.		2,795,298 (2004)		http://www.bcstats.gov.bc.ca/data/sep/fraser/fb_ROBC.pdf		Provided by NDM
7	**Human Settlement**	Native population	Fraser Basin Statistical Profile	BC Stats	2001	Fraser Basin Statistical Profile, Prepared by BC Stats.		85,278 (2001)		http://www.bcstats.gov.bc.ca/data/sep/fraser/fb_ROBC.pdf		Provided by NDM
8	**Industrial Devlopement**	Mining operations		Fraser Basin Council.				8 major mines producing 60% of B.C.'s metal mine production		http://www.fraserbasin.bc.ca/fraser_basin/index.html		Provided by NDM
9	**Industrial Devlopement**	Pulp and paper operations		MOE				11 major mill operations		http://www.env.gov.bc.ca/epd/epdpa/industrial_waste/forestry/papp.html		Provided by NDM
10	**Industrial Devlopement**	Hydroelectric operations	Email from Aaron Cruikshank, Stakeholder Engagement Coordinator, BC Hydro.	BC Hydro		Email from Aaron Cruikshank, Stakeholder Engagement Coordinator, BC Hydro.		8 hydroelectric facilities generating 879 MW of power		aaron.cruikshank@bchydro.bc.ca		Provided by NDM
11	**Industrial Devlopement**		Health of the Fraser River Aquatic Ecosystem, Vol. II .	FRAP	1998	Health of the Fraser River Aquatic Ecosystem, Vol. II .A Synthesis of Research Conducted under the Fraser River Action Plan. DOE (Environment Canada) FRAP 1998-11.		25 major dams (9m or greater in height)		http://www.rem.sfu.ca/FRAP/S_cov.pdf.		Provided by NDM
12	**Industrial Devlopement**	Sewage treatment plants	State of the Basin Address	Fraser Basin Council	2000	State of the Basin Address, Presented by Iona Campagnolo, November 2000.		90		http://www.fraserbasin.bc.ca/programs/documents/SOFB2000_BasinAddress.pdf		Provided by NDM
13	**Industrial Devlopement**	Agriculture	2004 State of the Fraser Report, Sustainability Snapshot 2.	Fraser Basin Council	2004	2004 State of the Fraser Report, Sustainability Snapshot 2. Fraser Basin Council, 2004, p. 5.		10,000 farms		http://www.fraserbasin.bc.ca/publications/2004-Snapshot2.pdf		Provided by NDM
14	**Industrial Devlopement**	Certified airports		Transport Canada.				11 airports in basin		http://www.tc.gc.ca/pacific/air/airport/menu.htm		Provided by NDM
15	**Biological**	Wildlife		World Wildlife Fund.				caribou, coyote. moose, black bear, bighorn sheep, wolf, muskrat, lynx, grouse, black-tailed deer		http://www.worldwildlife.org/wildworld/profiles/terrestrial/na/na0514_full.html		Provided by NDM
16	**Biological**	Salmon species	Fish Stocks of the Pacific Coast	DFO	2001	Fish Stocks of the Pacific Coast, Department of Fisheries and Oceans Canada, 2001.		5 species including coho, sockeye, chinook, chum, pink; also steelhead. Provides a good overview of stock status of the commercial salmonids and provides a discussion on the Fraser System for each. If mining is mentioned it is only listed as a minor factor in reduced populations, forestry, urban development and agriculture are the main factors.		http://www-comm.pac.dfo-mpo.gc.ca/publications/speciesbook/PacificFishStocks.pdf		Provided by NDM
17	**Biological**	Other fish species		Fraser Basin Council.				65		http://www.fraserbasin.bc.ca/		Provided by NDM
18	**Biological**	Bird species		Fraser Basin Council.				more than 300 species supported		http://www.chrs.ca/Rivers/Fraser/Fraser-St_e.htm		Provided by NDM
19	**Biological**	Sockeye	Report of the Fraser River Panel	Pacific Salmon Commission						http://www.psc.org/publications_annual_fraserreport.htm		Provided by NDM
20	**Biological**	Sockeye	Annual Reports.	Pacific Salmon Commission						Provided by the Pacific Salmon Commission.		Provided by NDM

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1	Topic-General	Topic-Specific	Report Title	Source	Year	Citation	Mention Mining?	Summary	Data Quality	Location of Article	Digital Version Available?	Reviewer (initial)
21	Biological	Chinook	Report on the PSARC Salmon Subcommittee meeting, November 14-16, 2000	DFO	2000	Department of Fishereis and Oceans Canada. 2000. Report on the PSARC Salmon Subcommittee Meeting, November 14-16, 2000. Eds. M. Stocker and A. MacDonald. Pacific Biological station, Nanaimo, BC	No	review of document re. early returning Fraser chinook. Report rejected by committee. No data, no discussion.	NA	AECOM		SH
22	Biological	Chinook	Summary of Stock Assessment Information for Selected Early Returning Chinook Salmon Populations for the Fraser River Watershed	DFO	2001	Bailey, R., J. Irvine, J. Candy, C. Parken, S. Lemke, M. Sullivan, M. Wetklo. 2001. Summary of Stock Assessment Information for Selected Early Returning Chinook Salmon Populations for the Fraser River Watershed. Departmenr of Fisheries and Oceans. Science Branch, Stock Assessment Division, Kamloops BC.	No	Reviewed Birkenhead, Spius, Coldwater and upper Chilcotin. No indication of temporal pattern in data analyses, although low escapements for each population are present. Most harvest occursin lower Fraser First Nation fishery	Low for all but Birkenhead.	AECOM	Y	SH
23	Biological	Chinook	Stock Status Report D6-11	DFO	1999	Department of Fisheries and Oceans. 1999. Stock Status Report D6-11 (1999) Fraser River Chinook Salmon DFO Science, Pacific Region.	No	Lots of info re. coasted wire tagging and recovery, contributing to determination of migration and catch location of each individual stock. Harrison stocks are numerically dominant, and returns are highly variable. Non Harrison stock aggregates increased in mid-1980s, with Thompson increasing more than upper and mid-Fraser likely due to CO conservation measures and declines in late SK fisheries.	Low as most chinook escapement data is based on visual surveys which are baised to low counts, but are considered precise.	AECOM	Y	SH
24	Biological	Chinook	A discussion paper on possible new stock groupings (Conservation Units) for Fraser River Chinook Salmon	DFO	2002	Bailey, R., J Irvine. C. Parken, S. Lemke, R. Bailey, M. Wetklo, K. Jonsen. 2002. A discussion paper on possible new stock groupings (Conservation Units) for Fraser River Chinook Salmon. Department of Fisheries and Oceans. Science Branch, Pacific Biological Station	No	Proposes various stock groupings for Fraser Chinook for further ideintification of conservation units below the species level, including consideration of genetics, productivity and managability of various stocks. Includes detailed discussion of genetics. Focus on natural spawning groups.	Table 6.1.1 identifies higher productivity populations Table 6.3 Includes counts of peak passage through Albion in 2001. Lots of data on genetics.	AECOM	Y	SH
25	Biological	Chinook habitat	Habitat-based methods to estimate spawner capacity for chinook salmon in the Fraser River watershed	DFO	2002	C. Parken, J. Irvine, R. Bailey, I. Williams	No	Insufficeint data currently exists to determine escapement from a stock-recuitment approach. So habitat models are developed to produce spawner capacity. Freshwater rearing habitat does not limit Fraser CH populations as juvenile disperse through all avaliable habitats, which are substantial. Spawning habitat may be limiting as CH are displaced to low quality areas during high escapements	Table 1 (Appendix) contains biophysical data for spawning system groups; table 5 contains spawning density #'s for Nicola and Lower Shuswap; Table 6-8 contains spawner capability and max escapement predictions based on new model.	AECOM	Y	SH
26	Biological	Sockeye	Historical adult spawners data for Fraser River sockeye stocks by cycle year	PSC/DFO	2008	T. Cone Spreadshet	No	Historical sockeye spawner escapement for all major stocks from 1938 to 2003.	Early low, more recent high. Prior to 1954 major systems surveyed only. Most early data collected using aerial, foot, or fence counts. Since inception of Pacific Salmon Commission in 1985 Lower Fraser testfisheries at Whonnock and Mission bridge acoustical data are source of numbers. Before 1999 stock proportion data was developed from scale analysis. 2000 and later stock proportion has been supplemented with genetic analysis	AECOM		PL
27	Biological	Sockeye	Here We Go Again... Or the 2004 Fraser River Salmon Fishery	DFO	2004	Here We Go Again... Or The 2004 Fraser River Salmon Fishery, Report Of The Standing Committee On Fisheries And Oceans, Tom Wappel, M.P. Chairman Document	not mining related	1992 Pearse-Larkin Report, The 1994 Fraser River Sockeye Public Review Board, The 1996 Van der Peet Decision, The 1999 Report of the Auditor General of Canada, The 2002 Post-season Review, The 2002 Johnstone Strait Protest Fishery, Reports of the Commissioner for the Environment and Sustainable. Development and the Auditor General of British Columbia); Life Cycle of the Sockeye Salmon; Process of Estimating Sockeye Salmon Runs and Escapements; The 2004 Fraser River Sockeye Salmon Run and Harvest; Possible Explanations for the Problem Encountered in 2004;(Inaccurate Counting, The Temperature of the River,	98 pages, good data	http://www.parl.gc.ca/infocomdoc/Documents/38/1/parlbus/commbus/house/reports/foporp02/foporp02-e.pdf	Y	RF
28	Industrial Devlopement	health of river	Fraser River Action Plan	Environment Canada	no date	Fraser River Action Plan, Environment Canada	not mining related	some abandoned contaminated sites mentioned	not a lot of data	AECOM	N	RF
29	Industrial Devlopement	health of ecosystem	State of the Environment report For British Columbia	Province of BC	1993	State of the Environment report For British Columbia, Province of BC, Environment Canada, 1993	not mining related	nothing specific to Fraser River and mining				

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30	Biological	Sockeye	2004 Southern Salmon Fishery Post - Season Review, PART ONE FRASER RIVER SOCKEYE REPORT	Committee report, Chaired by Bryan Williams, QC.	2005	2004 Southern Salmon Fishery Post - Season Review, PART ONE FRASER RIVER SOCKEYE REPORT March 2005	mining not mentioned in report	Good report documenting the low sockeye escapement in 2004, 91 pages. Note: Summarizes the problem assoc. with years when there was unexpected high and low (I.e. 1994, 98 & 02) escapement reaching spawning grounds. Indicated priamry problems are related to natural environmental conditions such as high water temp. in the river and poor estimate of in-river harvesting.	good data	AECOM	Y	RF
31	Biological	salmonids	Impacts of acid mine drainage on juvenile salmonids in an estuary near Britannia Beach in Howe Sound	Can. J. Fish. Aquat. Sci.	2000	G. Elizabeth Piercey, Impacts of acid mine drainage on juvenile salmonids in an estuary near Britannia Beach in Howe Sound Can. J. Fish. Aquat. Sci. 57: 2032–2043 (2000)	NOT Fraser River issue, mining related	Impacts of acid mine drainage on juvenile salmonids in an estuary ne	good data	AECOM	Y	RF
32	Industrial Devlopement	Fish Habitat	Sand and Gravel Management and Fish-Habitat Protection in British Columbia Salmon and Steelhead Steams.	Pacific Fisheries Resource Conservation Council.	2000	Rosenau M, Angelo M. 2000 (and 1999). Sand and Gravel Management and Fish-Habitat Protection in British Columbia Salmon and Steelhead Steams. Vancouver, BC: Pacific Fisheries Resource Conservation Council.	Metal mining yes, and habitat destruction in lower Fraser resulting from in stream mining	Because of the importance of sediments to the maintenance of salmon & steelhead trout habitats, this report first reviews what constitutes in-stream fish habitat. It describes the influence of the ice age on sediments in salmonid streams, the role of sediment in those streams (provision of spawning grounds & fish-rearing habitat, producing insects for fish food), and how sediment processes in streams create salmonid habitat. The report then discusses the impacts on fish habitat of human actions such as gravel mining, removal of floodplain sediments for flood protection, dam construction, and dredging for navigation. Since these behaviours are regulated by governments, the report goes on to examine government agency roles, responsibilities, & activities, including those meant to ensure no net loss of fish habitat, as they relate to legislation, policy, & regulation. A case study of sediment management in the lower Fraser River is included. "Disruption of sediment processes by means of human intervention has occurred in British Columbia through a variety of means including: gravel and **metal mining**, diking and armoring of stream banks, damming, and dre	Good report	AECOM	Y	RF
33	Rivers	endangered rivers	BC's Most Endangered Rivers List of 2004	Outdoor Recreation Council of BC	2004	BC's Most Endangered Rivers List of 2004 Mark Angelo, Rivers Committee Chair, Outdoor Recreation Council of BC	yes, metal mining	lists mining as impact to rivers and fish for Taku., Ashlu, and Fraser River (gravel mining)	little information	AECOM	Y	RF
34	Fisheries Management	Sockeye salmon	Pacific Region, Integrated Fisheries Management Plan, Salmon,	DFO	2005	Pacific Region, Integrated Fisheries Management Plan, Salmon, Southern B.C. , June 1, 2005 - May 31, 2006, DFO	mining not mentioned	This 2005/2006 Southern B.C. Salmon IFMP covers June 1, 2005 to May 31, 2006 for First Nations, recreational and commercial fisheries for Pacific salmon in the southern areas of B.C. It includes the Fraser River watershed. Pacific salmon species covered in the plan include sockeye, coho, pink, chum and chinook salmon. Includes: management of Pacific salmon fisheries in southern B.C., decision guidelines, contains department contact list and a list of websites, 134 pages		2005 Salmon Rpt by DFO.pdf	Y	RF
35	Industrial Devlopement	water quality	The Uncertain Future of the Lower Fraser	Westwater Research centre	1976	Dorcey, A., The Uncertain Future of the Lower Fraser, Westwater Research Centre, 1976	not clearly mentioned	Considers pollution control on the lower fraser, current conditions, treatment of pollution sources, limitations on pollution sources, framework of law and public agencies are required.	high	AECOM	N	RF
36	Industrial Devlopement	Fish Habitat	The Fraser Basin Sustainability through responsibility	DFO	no date	DFO, The Fraser Basin Sustainability through responsibility	mining section	Urban development, Agriculture, Forestry, manufacturing, mining, transportation and dams. Mining: 40 mineral mines operate in Fraser River basin, exploration activities and road buildings, increased sedimentation largest threat, mentions cyanide spill killing fish in Coquihalla River (under built dam) - SEARCH. Describes habitat regions of Fraser: lower fraser, thompson/interior, middle fraser and upper fraser				
37	Industrial Devlopement	mining spill	1982 Legislative Session: 4th Session, 32nd Parliament HANSARD	Bc government	1982	N/A	about cyanide mining spill killing fish	**MR. SKELLY** : ... Carolin Mines cyanide spill. **MR. SKELLY** : **In view of the almost total loss of the summer steelhead stock in the Coquihalla and the continuing losses of species which prey on poisoned fish, as well as the loss of safe domestic water supplies for people living in the area**, has the minister decided to recover costs from Carolin Mines in order to restore the resources to their original quality and state, and has he decided to lay charges under the Pollution Control Act? **HON. MR. ROGERS** : I believe I said earlier that the decision on whether or not to lay charges has not yet been made. I expect it will be made within the next two to three days. A decision on whether or not we will try to get compensation for charges will also be made at that time.	no data	http://www.legis.gov.bc.ca/Hansard/32nd4th/32p_04s_820413p.htm#06965	Y	RF

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38	**Industrial Devlopement**	Fish Habitat	THE GOVERNMENT OF CANADA'S FAILURE TO ENFORCE THE FISHERIES ACT AGAINST MINING COMPANIES IN BRITISH COLUMBIA	Sierra Legal Defence Fund	1998	THE GOVERNMENT OF CANADA'S FAILURE TO ENFORCE THE FISHERIES ACT AGAINST MINING COMPANIES IN BRITISH COLUMBIA, Sierra Legal Defence Fund, 1982	yes	The Department of Fisheries and Oceans and Environment Canada, the federal departments responsible for environmental enforcement in B.C., have not prosecuted any mining companies in B.C. for violations of s. 36(3) of the *Fisheries Act* for at least ten years.1 Although this Submission will focus on the Tulsequah Chief, Mount Washington and Britannia mines, there are at least twenty other acid-generating mines in B.C. where violations of s. 36(3) of the *Fisheries Act* either may have occurred or may be occurring without any enforcement action being taken	legal arguments with reports attached	98-4-SUB-OE mining impacts in fish _ taking DFO to court.pdf	Y	RF
39	**Industrial Devlopement**	Fish Habitat	Living Blueprint for BC Salmon Habitat	Independent panel, pacific salom foundation	1998	Independent panel, Living Blueprint for BC Salmon Habitat, 1998	not obvious	Habitat Protection is required for wild salmon, 8 volunteers of the independent panel wrote this report trying to promote salmon sustainability	high	AECOM	N	RF
40	**Physical**	Land area, water, discharge, parkland	Health of the Fraser River Aquatic Ecosystem, Vol. II .	Environment Canada	1998	Health of the Fraser River Aquatic Ecosystem, Vol. II .A Synthesis of Research Conducted under the Fraser River Action Plan. DOE (Environment Canada) FRAP 1998-11	not mining related	Phamphlet - 234,000 sq km, 1,375 km of river length, 13 major tributaries, 3,600 m3/s, 6% of land area is provincial parkland (1991)	summary data	http://www.rem.sfu.ca/FRAP/S_cov.pdf.		RF (from Sam)
41	**Human Settlement**	Population base	Fraser Basin Statistical Profile	BC Stats	2004	Fraser Basin Statistical Profile, Prepared by BC Stats.	not mining related	statistical population data- Native population 85,278 (2001), Population base 2,795,298 (2004)	not much, 10 pages	http://www.bcstats.gov.bc.ca/data/sep/fraser/fb_ROBC.pdf		RF (from Sam)
42	**Biological**	Sockeye	Fraser River sockeye catch and exploitation rates by stock	PSC/DFO	2006	V. Keong P. Ryall. Spreadsheet	No	Historical sockeye exploitation for all major stocks from 1952 to 2004	Med. Data fairly comprehensive, taken from fish plant records and stock seperation done via scale analysis and recently genetic analysis. Some info may be estimates. Constantly being updated as information surfaces.	AECOM		PL
43	**Biological**	Pink	Fraser River Pink salmon escapement and exploitation numbers 1959-2005	PSC	2006	B. White Fraser Pink salmon historical data spreadsheet.	No	Historical escapement and exploitation for Fraser Pink salmon from 1959-2005.	Exploitation data from fish plant records, escapement data through foot, aerial , and fence counts and in later years testfisheries. Same numbers for Pink as PBS data, which was derived from BC16.	AECOM		PL
44	**Biological**	All Species	Escapement numbers for all species of Fraser Pacific salmon from 1950-2003	PBS	2006	B. Ford spreadsheet containing nuseds Fraser salmon data.	No	Historical escapement from BC16 data.	Low to High, depending on species and method collected. Although no mention of methodology.	AECOM		PL
45	**Biological**	Chinook	Chinook Technical Committee ESC13	Richard Bailey, DFO	2006	N.D. Schubert Chinook technical committee spreadsheet.	No	Historical escapement and abundance of Fraser Chinook salmon from 1951-2003.	Med to High. More description of stocks and methodology than BC16 data. Visual and Mark Recapture used.	AECOM		PL
46	**Biological**	Coho	Interior Fraser Coho	Richard Bailey, DFO	2006	M. Chamberlain spradsheet containing hisorical coho escapement and exploitation.	No	Historical Escapement and derived exploitation rates for Interior Fraser Coho salmon from 1974-2004.	Med to High. More description of stocks and methodology than BC16 data.	AECOM		PL
47	**Biological**	Data Validity on salmon stock assessment	Stock Status Report D6-13 (2002)	DFO	2002	DFO Sakinaw Lake Sockeye Salmon Stock Status Report D6-13(2002)	No	Validity of BC16 data in stock assessment	A time series of spawner escapement estimates from BC16 reports has been used because these reports are based on fishway counts with reasonably consistent monitoring since 1953.	AECOM		PL
48	**Biological**	Data Validity on salmon stock assessment	1999 Assessment of Thompson River/Upper Fraser Coho Salmon	Canadian Stock Assessment Secretariat	1999	J.R. Irvine et al. 1999. Canadia Stock Assessment Secretariat Research Document	No	There are many examples where stream inspection logs show no fish being observed for a particular creek, yet annual escapement reports (i.e. BC16) show fish present. In Harris Creek 1995, 1 fish was counted, but the reported BC16 estimate was 75.	High	AECOM		PL
49	**Biological**	Fraser chum salmon escapement numbers.	Historical Fraser chum escapement levels.	DFO	2005	M. Sullivan. Spreadsheet containing historical chum escapement.	No	Historical escapement levels for Fraser river, some stock seperation.	Recent numbers, 1998 and later very good , result of Albion testfishery. Earlier numbers averages.	AECOM		PL
50	**Biological**	Lake Enrichment Programs	Factors Limiting Juvenile Sockeye Production, and Enhancement Potential for Selected BC Nursery Lakes.	DFO	2001	K.S. Shortreed et al. 2001. Canadian Stock Assessment Secretariat Research Document	No	Gives historical Lake enrichment program information in BC and the responses by the lake.	High	AECOM		PL
51	**Biological**	Alouette Resevoir Fertilization Program	Alouette Resevoir Fertilization Program	BC Hydro	2006	Website	No	Gives years and results of program.	High	http://www.alouetteriver.org/News/partners/fertilization.htm		PL

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52	**Physical**	Hell's Gate River blockage, fish declines and subsequent recovery	BC Examples of river recovery.	River Recovery from BCIT	2002	Website	No	In 1913, rock debris from railway construction at Hell's Gate stopped thousands of salmon from travelling up the Fraser's mainstem to spawn. Salmon runs on the Upper Fraser were decimated in the years that followed. In 1946, Canadian and American funds were used to build elaborate fish ladders at Hell's Gate, which saved many runs from extinction and allowed fish stocks to rebuild.	Good, historical evidence.	http://www.recovery.bcit.ca/bcie.html		PL
53	**Physical**	BC's endangered rivers	BC's most endangered rivers list of 2004.	Mark Angelo Rivers Commite Chair of Outdoor recreation Council	2004	M. Angelo 2004 Endangered Rivers List 2004.	Yes	Rivers advocates have expressed concern about acid leechate problems, particularily in light of past leechate problems associated with earlier mining activity in the area of the Taku River.	Good	AECOM		PL
54	**Physical**	Acid Mine Drainage	Impacts of acid mine drainage on juvenile salmonids in an estuary near Britannia Beach in Howe Sound, British Columbia		2000	K.L. Barry et al. 2000. Fisheries and Oceans Canada, Science Branch	Yes	The abandoned copper mine at Britannia Beach, British Columbia, has been releasing acid mine drainage (AMD) into Howe Sound for many years. Water quality near Britannia Creek was poor, particularily in spring when dissolve Cu exceeded 1.0 mg/L an pH was less than 6. Beach seine surveys during April-Agust and March-May showed that chum salmon abundance was significantly lower near Britannia Creek mouth than in reference areas. Juvenile chinook salmon placed in surface cages near Briannia Creek showed 100% mortality in 2 days.	Good	AECOM		PL
55	**Physical**	Mine Tailings	Preliminary report on the effects of abandoned mine tailings at Wells BC, on the aquatic ecosysem of Jack of Clubs Lake. Part 1: Reconnaisance Study.	FRAP	1993	A. Murdoch et al. Geologic Survey of Canada Lake Research Branch Research Report.	Yes	Mining produces waste products that contain naturally occuring and potenially toxic elements. A peak in certain elements is likely from past gold mining operations. Mining waste products are being sudied to research groundwater possible contamination	Good	AECOM		PL
56	**Physical**	Mining waste water	Recommended guidelines for wasewater characterization in the Fraser River basin.	FRAP	1993	Prepared for Environment Canada by Norecol Environmental Consultants LTD	Yes	There is the potential for lead to be present in mining and metal processing effluents.	Good	AECOM		PL

Author's Biographies

Bruce S. Ford, Senior Environmental Biologist, M.R.M, R.P. Bio. Mr. Ford is a senior biologist with AECOM. He has over 25 years of experience primarily in fish and fish habitat studies, environmental permitting and approvals and environmental impact assessments. Projects include studying the environmental effects of urban and industrial project development including mining projects. He has worked on projects throughout western and northern Canada including many projects within the Fraser River Watershed. He has also conducted studies and prepared reports on live capture technologies for the capture of Pacific Salmon, guidelines for the protection of fish and fish habitat at small hydroelectric developments and a compilation of best management practices for environmentally sustainable mining practices in Northwest Territories. Mr. Ford has a Master's degree (MRM) in Resource and Environmental Management from SFU where he studied fisheries management and factors influencing freshwater sport fishers.

Jennifer Sarchuk, Aquatic Biologist, B.Sc., Dip. Tech., AECOM. Ms. Sarchuk is a biologist with AECOM and has both an academic and a technical background. Prior to joining AECOM, Ms. Sarchuk salmon related experiences included working as a deckhand on a commercial salmon boat on the Stikine River, as a port sampler for Pacific Salmon Commission and various other salmon related volunteer work (egg takes and tagging programs). Since joining AECOM, Ms. Sarchuk has been involved in biological field programs that support environmental baseline studies, including fish and fish habitat assessments, water quality sampling, and hydrometric data collection in Northern British Columbia, Yukon and Nunavut for several mining projects. From these projects, she has been involved in both collecting and analyzing the data.

Attachment 5
Offsetting Potential Wetlands Impacts through the Environmental Permitting Process

White Paper No. 5
Topic: Wetlands Mitigation
Title: Offsetting Potential Wetlands Impacts through the Environmental Permitting Process
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Executive Summary

The purpose of this white paper is to summarize various approaches for offsetting potential impacts on wetlands and related waterbodies (lakes, ponds, steams, and marine waters), hereafter referred to as "wetlands," associated with development projects in Alaska. As such, this white paper focuses on the regulatory requirements and mitigation options for projects in Alaska and provides examples of possible compensatory mitigation opportunities that could result from mining and other development in the Bristol Bay region.

Wetlands cover more than 40% of Alaska (USFWS, 1994). These wetlands perform important ecological functions and current environmental laws and regulations require compensatory mitigation for impacts to those functions. Specific mitigation requirements are described in the U.S. Army Corps of Engineers' (Corp) Compensatory Mitigation for Losses of Aquatic Resources Rule, codified at 33 C.F.R. Part 332.

The Compensatory Mitigation Rule outlines a sequence for analyzing and mitigating impacts to wetlands: avoid and minimize impacts to the maximum extent practicable, and then perform compensatory mitigation to offset any remaining impacts that cannot be avoided. Before permits can be issued, a formal mitigation plan must be approved by the Corps.

Any resource development project in Alaska is required to complete a thorough permitting process. For mining developments, this process includes a wetlands mitigation plan, closure and reclamation plan, and payment of bonds for financial assurance for reclamation of the entire project. Compensatory mitigation for wetlands impacts could, for example, take the form of anadromous fish habit restoration, property acquisition for conservation easements, water quality improvements, remediation of contaminated sites, biodiversity offsets, funding for research and education, or other options. There may be opportunities for development organizations to join with local tribal governments and non-governmental organizations to create wetland mitigation banks or endowment funds to manage fish and wildlife, water quality, and preservation of undeveloped natural resources for generations to come.

Throughout Alaska there are numerous important development projects currently being planned, including mines, renewable energy sources, oil and gas facilities, and public infrastructure. Wetlands are ubiquitous in Alaska and most of these projects will be required by law to have mitigation plans to offset unavoidable impacts to wetlands. This paper provides a conceptual picture of on how such projects may progress, while meeting regulatory and other environmental considerations.

1. Introduction

This white paper on regulated wetlands and related water bodies provides an overview for how potential impacts from development projects can be offset through the environmental permitting process. A brief description of the federal regulatory permitting program is provided to illustrate when impacts to wetlands and other water bodies must be mitigated, and how compensatory mitigation is addressed through the permitting process. Regulatory guidance specific to Alaska is discussed to illustrate unique best practices for mitigating wetlands impacts within the state.

The permitting process includes a phase called sequencing, which requires all development activities to avoid impacting wetlands if possible, minimize impacts that cannot be avoided, and then by fully considering the impacted wetlands' ecological functions, provide compensatory mitigation to offset the remaining impacts. Compensatory mitigation can take the form of restoration, enhancement, and preservation. Concepts for compensatory mitigation opportunities that could be adopted by future development projects, like the Pebble Project, in Bristol Bay or throughout Alaska are discussed. These concepts could include, for example, restoration and enhancement of stream habitats, increasing fish populations by removing barriers to fish passage, or preservation of high value habitats through third party-partnerships. This paper does not purport to recommend mitigation approaches or conceptual plans for the Pebble Project. Rather, it shows how existing environmental laws and regulations require development projects to offset impacts to wetlands.

2. Regulatory Context

Development activities in wetlands and other water bodies are regulated through federal environmental laws and policies. This section provides a basic background and context for this subject. Since development projects that could adversely affect wetlands are legally required to offset those impacts through compensatory mitigation plans, this discussion provides a foundation for the current regulatory practice that allows compensatory mitigation to relate to the ecological role, or "function," that wetlands perform in the environment.

2.1 Nationwide Regulations

Section 404 of the Clean Water Act (CWA), 33 U.S.C. § 1344, establishes a permitting program to regulate the discharge of dredged or fill material into waters of the United States, including wetlands. For ease of reference, the term 'wetlands' as used throughout the balance of this document includes all waters of the United States as defined by the U.S. Army Corps of Engineers (Corps) in 33 C.F.R. § 328.3 (including streams, tributaries, ponds, wetlands, etc.). The Corps administers the Section 404 permitting program in Alaska, using guidelines promulgated by the U.S. Environmental Protection Agency (EPA) pursuant to 33 U.S.C. § 1344(b)(1) to facilitate the Corps' permitting review. Example activities in waters of the United States regulated under this program include fill for development, water resource projects (such as dams and levees), infrastructure development (such as highways and airports), and mining projects.

To be permitted under the Corps' regulations, all projects must demonstrate, to the extent practicable, that steps have been taken to avoid wetland impacts, that potential impacts on wetlands that cannot be avoided have been minimized, and that mitigation for any remaining unavoidable impacts will be provided. This is known as sequencing under the Corps' permitting program. Proposed activities are regulated through a rigorous permit review process that takes into account a variety of factors, including wetland impacts, fish and wildlife habitat, land use, mineral needs, economics, and other considerations. 33 C.F.R. § 320.4(a) provides further details on this topic.

The most recent and comprehensive federal guidance concerning wetland mitigation under the Section 404 permitting program is contained within the Compensatory Mitigation for Losses of Aquatic Resources Final Rule, adopted in 2008 and codified at 33 C.F.R. Part 332 (Compensatory Mitigation Rule). The Compensatory Mitigation Rule, developed jointly by the Corps and EPA, establishes a hierarchy of preferred compensatory mitigation options. It states that mitigation for impacts should seek to provide for "no net loss" of wetland "functions" and that consolidated mitigation options, such as mitigation banks and in-lieu fee programs are preferred over smaller project-specific compensatory mitigation. The Compensatory Mitigation Rule also supports use of a watershed approach to evaluate maintenance of the chemical, physical, and biological integrity of the nation's waters, and helps ensure that current mitigation planning addresses impacts to wetlands based on "ecological function" as opposed to "area" replacement as had been the previous benchmark. The Rule provides significant flexibility for projects to propose off-site or out-of-kind compensatory mitigation where this mitigation may be more beneficial for a broader geographical area.

2.2 Alaska-specific Regulations

In response to the Compensatory Mitigation Rule, the Alaska District of the Corps released an Alaska District Regulatory Guidance Letter (RGL ID No. 09-01) in 2009, which provides a framework for compensatory mitigation planning and implementation in Alaska. While the Compensatory Mitigation Rule prioritizes the three primary forms of compensatory mitigation, establishing a preference for the use of mitigation banks first, followed by in-lieu fee programs and finally permittee-responsible mitigation, the Alaska RGL allows for flexibility between these three forms of mitigation and within each form.

Alaska, compared to much of the United States, is largely undeveloped and preservation is often the most practical, and sometimes the only form of mitigation. Preservation projects in Alaska have been accomplished through the structure of mitigation banks, in-lieu fee programs, and also through the permittee. For example, the few mitigation banks operating in Southcentral Alaska, the most developed region of the state, are predominantly conservation easements rather than restoration properties. This tendency toward preservation does not exclude opportunities for habitat restoration or enhancement when those opportunities exist. The flexibility written into Alaska's RGL allows project planners and agency reviewers to evaluate mitigation options considering their merits, including ecological benefits, without being encumbered by a preference for the form of mitigation.

For example, the Port of Anchorage expansion (Anchorage, Alaska) purchased credits from a mitigation bank and from an in-lieu fee sponsor (who in turn partnered with a tribal corporation) to preserve 5,000 acres of floodplain habitat. The expansion also involved two permittee-responsible mitigation projects. The permittee-responsible mitigation projects are notable because they were both off-site and out-of-kind mitigation projects located miles upstream from the impact areas. The justification for off-site and out-of-kind mitigation was to direct benefits for anadromous fish migrating from near the impact area in Cook Inlet to spawning and rearing areas in the Knik and Matanuska Rivers.

Currently, there are only four approved mitigation banks in Alaska, and three are within the Southcentral region of the state. One in-lieu program is currently authorized to operate in the Bristol Bay region.

Given the limited pool of mitigation banks and in-lieu fee providers in Alaska, permittee-responsible mitigation is an acceptable form of compensatory mitigation to the Corps' Alaska District. With permittee-responsible mitigation, the permit applicant is responsible for ensuring the long term success of the project, including, for example, the establishment of funding mechanisms and conservation easements. Permittee-responsible mitigation in Alaska often takes the form of preservation because in some watersheds there are limited opportunities for enhancement or restoration. Preservation can satisfy no-net loss objectives by elevating the legal protection surrounding a property's title. This can involve transferring the management and ownership of the property to a public agency or non-profit organization with a land conservation mandate.

The Compensatory Mitigation Rule also emphasizes that mitigation should occur within the same watershed as the area of impact, for the purpose of maintaining or preferably improving the overall ecological health of that watershed. Within Alaska and other Corps districts, the requirements that determine the geographic size of a watershed are flexible; watersheds are scaled during the permitting process. For example, the Conservation Fund, a nonprofit in-lieu fee provider is currently proposing to divide the state into five services areas based on large scale regional watersheds. Under that program, the Bristol Bay watershed, the Kuskokwim River watershed, Kodiak Island, and the Alaska Peninsula are grouped into one service area called Southwest Alaska. The regional scale of this "watershed" makes sense because development projects are scattered across an extensive and sparsely populated area, the ecological resources are similar, and mitigation opportunities can be clustered for greater ecological benefit.

Similar flexibility by the Corps regarding the form of mitigation (mitigation banks, in-lieu fee, or permittee responsible) and the scale of the watershed may provide significant benefit to Bristol Bay and Western Alaska by allowing future development projects to proceed; the collective value of the required compensatory mitigation could enhance existing resources. This is the kind of flexibility that is reflected in the Alaska Corps District's regional guidance (RGL ID No. 09-01).

3. Functional Assessments Support Mitigation Planning

Fill activities with temporary or permanent impacts to wetlands are required by Section 404 of the CWA to evaluate the ecological functions those wetlands perform. This process, commonly referred to as functional assessment, is intended to identify the role wetlands play in supporting the chemical, physical, and biological integrity of the wetlands that could be adversely affected by the project or fill activity. The results of the functional assessment can inform mitigation planning by accounting for functions potentially degraded or lost and for functions improved, restored, or protected through mitigation projects. For instance, a functional assessment could reveal that certain wetland types in a project area play a significant role as fish-rearing habitat. One mitigation strategy may then be to devise a restoration plan to develop new fish-rearing habitats and therefore replace that function.

During permitting, losses to wetland functions are offset by selecting mitigation that provides the same ecological functions at an equivalent and often greater amount. Mitigation that provides wetland functions at a greater value than existing conditions is referred to as "functional lift;" when this occurs, the project results in a net gain to the environment. Accounting systems have been established in Alaska and in other Corps districts with set standards for mitigation ratios. The ratios are inherently conservative to over-compensate for wetland losses. For example, when the functions of impacted and mitigated wetlands are equal, mitigation ratios in Alaska's RGL start at one to one and range up to three to one (some recent permits have required higher ratios). Mitigation options are then evaluated and selected, with agency involvement, to choose options that provide the greatest opportunity for ecological gain.

Mitigation is a continuum that occurs throughout the life of a project and is not merely an action completed following the project closure. By law, mitigation must address temporal as well as permanent impacts to wetland areas and ecological functions. After the permitting of a project, development occurs through the phases of construction, operation, and closure and that timeline drives compensatory mitigation. Mitigation is often an ongoing process where temporary project impacts can be addressed and mitigated well before project closure.

4. Possible Compensatory Mitigation Opportunities

Compensatory mitigation plans for development in Western Alaska will need the inherent flexibility written into RGL 09-01 and the creativity to look to other locations for mitigation measures that rely on the adversely affected watersheds. This section will identify examples of possible compensatory mitigation opportunities for development projects in the Bristol Bay and Western Alaska regions, with a particular focus on permittee-responsible restoration and enhancement and potential third-party partnerships. The following examples showcase wetland ecosystems, fish habitat, and migratory birds, although mitigation on any large scale project could include a wider range of options, as determined through the regulatory process. This section discusses fish mitigation with the understanding that wetlands mitigation planning and protection and enhancement of fish habitat are related efforts.

Permittee-Responsible Restoration Opportunities for Wetland Ecosystems: According to the Compensatory Mitigation Rule, restoration is the process of returning natural or historic functions to a wetland with a resulting gain in wetland acres and/or function. A restoration project will begin with the identification of current wetlands in need of repair. One example might be under-utilized upstream fish habitat due to inadequate or failed culverts that impair fish passage beneath historic roads (i.e., those constructed prior to current regulatory requirements and guidance, and engineering best practices). Improving fish passage by replacing outdated culverts using modern road construction and engineering methods could re-open upstream areas to migrating fish and provide viable restoration-based compensatory mitigation opportunities.

In any restoration-based mitigation project, the prospective permittee collaborates with State and Federal agencies to identify wetlands in need of restoration and agrees on approaches to address the existing cause of degradation. Once the projects have been identified, the permittee will work to restore the natural or historic wetland function that will increase wetland acres and/or function.

Permittee-Responsible Enhancement Opportunities for Wetland Ecosystems: The Compensatory Mitigation Rule defines wetlands enhancement as heightening, intensifying, or improving one or more wetland functions within existing wetlands that result in a gain in wetland function, but not an increase in wetland acres. Often, the permittee will select a specific wetland function upon which to focus enhancement, such as water quality. State and Federal agencies have a voice during the permitting process to make additional recommendations for wetlands projects in need of enhancement. There may be projects, for example, that reduce the amount of sediment, nutrients and other pollutants entering the watershed that enhance the downstream water quality and habitat for fish and other species. Under any enhancement project, the goal for the permittee is to heighten, intensify, or improve one or more functions within existing wetlands.

Third-Party Mitigation Opportunities for Wetland Ecosystems: The following organizations and initiatives provide examples of funding or partnership opportunities for restoration, enhancement, and preservation. These examples do not imply existing formal relationships with the Pebble Partnership, nor is this a comprehensive list. This list includes options within Bristol Bay and throughout Alaska.

- **Nushagak-Mulchatna Wood-Tikchik Land Trust** – http://nmwtlandtrust.org/ – The Nushagak-Mulchatna Wood-Tikchik Land Trust is dedicated to the preservation and protection of salmon and wildlife habitat of the Nushagak Bay watersheds located in the remote Bristol Bay region of southwestern Alaska, including the Wood-Tikchik State Park and the Togiak National Wildlife Refuge. The Land Trust was spearheaded by the Native Corporation Choggiung Ltd. This project may be an opportunity for very local preservation-based mitigation.

- **The Conservation Fund** – http://www.conservationfund.org/alaska_hawaii – The Conservation Fund started in 1985 as a smart solution to an old problem: how to balance environmental and economic goals. The Conservation Fund is the only Corps-approved in-lieu fee, statewide third-party sponsor. Below are examples of preservation mitigation projects The Conservation Fund has supported as an in-lieu fee sponsor.

  - In 2008, the Conservation Fund and its partners protected more than 12,500 acres of wetlands on the Alaska Peninsula by establishing Izembek National Wildlife Refuge. This refuge is internationally recognized for the importance of its wetlands. Izembek National Wildlife Refuge, at the tip of the Alaskan peninsula contains one of the largest eelgrass beds in the world. Working with the Conservation Fund to transfer additional acreage to the Izembek National Wildlife Refuge Complex would further support maintenance of the eelgrass ecosystem.

  - Alaska's Wood-Tikchik State Park – The Southwest Alaska Wild Salmon Initiative is working to place conservation easements or purchase property from willing land owners along the rivers and lakes in Wood-Tikchik. Some past projects include the addition of property at the start of the Agulukpak River and at the mouth of Elva Creek at Lake Nerka. The properties were considered highly valuable for development but both were also important spawning systems for tens of thousands of sockeye salmon. The adjacent wetlands and uplands are important to migratory birds and other wildlife.

- **Business and Biodiversity Offsets Program (BBOP)** - http://bbop.forest-trends.org/ - BBOP is a partnership between companies, financial institutions, governments and civil society organizations to explore biodiversity offsets. The BBOP states: "*biodiversity offsets are measurable conservation outcomes resulting from actions* *designed to compensate for significant residual adverse biodiversity impacts arising from project development and persisting after appropriate prevention and mitigation measures have been implemented"*. The goal of biodiversity offsets is to achieve no net loss, or preferably a net gain, of biodiversity on the ground with respect to species composition, habitat structure and ecosystem services, including livelihood aspects. This program may be an option for funding preservation mitigation projects.

Third-Party Mitigation Opportunities for Fish Habitat: Impacts by any large development project on fish habitat is a general concern to the residents of Bristol Bay and Alaska. Potential opportunities for partnering in off-site compensatory mitigation are diverse, including options of increasing the overall regional fisheries.

- Based on maps of salmon migration patterns of Western Alaska and the North Pacific, salmon from the Nushagak and Kvichak watersheds migrate to the southeastern Bering Sea (Andrews III and Farley, Jr. 2011). In this area of the Bering Sea, salmon from Bristol Bay, the Kuskokwim River, the Yukon River, Norton Sound, and the Kamchatka Peninsula (Russia) comingle until they migrate back to the spawning waters. Supporting the southeastern Bering Sea ecosystem would positively affect all fish from Western Alaska. A collaborative project supporting other Western Alaska commercial salmon fisheries may positively benefit the entire state.

    - Yukon River Drainage Fisheries Association – http://yukonsalmon.org/ – For conservation and restoration projects, the Yukon River Drainage Fisheries Association works to protect wild salmon stocks and the habitats upon which they depend. Through biological research and participation in management, this association works on behalf of Yukon River fisheries and may be a potential partner for restoration and enhancement mitigation projects.

    - Norton Sound Fisheries Research and Development Program – http://www.nsedc.com/nsfrdp.html – This program promotes scientific research in the Norton Sound region with an emphasis on supporting local fisheries. Projects in the past have worked to improve salmon stocks by rehabilitation of chum and Coho stocks through mist incubation and eye-egg planting, sockeye rehabilitation through lake fertilization, and multiple salmon-counting projects using weirs, towers, and sonar equipment. Collaboration with this program could benefit salmon migrating to the Bristol Bay watershed area.

    - Bering Sea Fisherman's Association – http://www.bsfaak.org/ – This group has programs in the Arctic Yukon Kuskokwim Sustainable Salmon Initiative and the Western Alaska Marine Salmon Studies that may be available for funding for restoration and rehabilitation mitigation projects.

- **NOAA Habitat Conservation** – https://alaskafisheries.noaa.gov/habitat/ – National Marine Fisheries Service's Habitat Conservation Division (HCD) works in coordination with industries, stakeholder groups, government agencies, and private citizens to avoid, minimize, or offset the adverse effects of human activities on essential fish habitat and living marine resources in Alaska. This work includes conducting and/or reviewing environmental analyses for a large variety of activities ranging from commercial fishing to coastal development to large transportation and energy projects. HCD focuses on activities in habitats used by federally managed fish species located offshore, nearshore, in estuaries, and in freshwater areas important to anadromous salmon. The HCD has a history of projects in Alaska and could partner on restoration, enhancement, and preservation projects.

Third-Party Mitigation Opportunities for Bird Habitat: Large-scale development projects in Alaska may adversely affect wetlands and other resources that provide bird habitat areas. The following are opportunities for compensatory mitigation that focus on bird habitats.

- **Audubon Alaska** – http://ak.audubon.org/ – Audubon Alaska has developed policy objectives that could integrate with mitigation opportunities in Western Alaska. These include efforts to: secure permanent protection for watersheds with high ecological and community values distributed across the Tongass National Forest; monitor threats to and defend significant bird populations and their habitats, emphasizing Alaska Watch List species and Important Bird Areas (IBAs); monitor threats to and defend important wildlife populations and habitats, especially in the National Wildlife Refuge system; and seek protection of internationally significant wildlife resources and their habitats in Alaska's Arctic marine environment, emphasizing the Bering, Beaufort, and Chukchi Seas. These IBAs support many of the species of conservation concern that breed in the Bristol Bay and Western Alaska area.

- **Conservation of Arctic Flora and Fauna Circumpolar Eider Conservation Strategy** – http://caffportal.arcticportal.or g/seabird-conservation -strategies – This conservation strategy program has been designed to protect key habitats to ensure continued viability on which eider populations depend. The current plan for this organization does not list key habitats or current projects, but this program may benefit from funding for preservation mitigation opportunities. Eiders are a bird that use wetlands in Western Alaska and may be adversely affected by large development projects in Western Alaska.

5. Conclusion

Any mineral resource development project in Alaska will have to go through a thorough and complex permitting process. This process outlines specific requirements to ensure the project addresses potential impacts to wetlands resources including a wetlands mitigation plan, closure and reclamation plan, and payment of bonds for financial assurance for reclamation of the entire project. There is precedent that mitigation plans can include traditional on-site projects for small or temporary impacts, and nontraditional off-site projects to compensate for large or permanent impacts. There is also precedent for support of large, federal, tribal, state, and nongovernmental organizations to collaborate on ecosystem restoration projects such as the Puget Sound Partnership, San Francisco Bay Joint Venture, Great Lakes Protection Fund, Everglades Foundation, and Central Valley Joint Venture. Given the number of large, proposed development projects in Western Alaska, there may be an opportunity for development organizations to join with local tribal governments and nongovernmental organizations to create mitigation banks and endowment funds to preserve and enhance undeveloped natural resources for generations to come while ensuring and promoting necessary economic development for the entire region.

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Author Biographies

Chris Wrobel | HDR

Chris is a terrestrial ecologist with over 12 years of experience as an environmental professional in Alaska. He has a BA degree from Kalamazoo College and extensive post-degree coursework and professional training specific to environmental and wetlands science. Chris has worked for the US Fish and Wildlife Service studying the recovery of seabird colonies in the Barren Islands after the Exxon Valdez Oil Spill. He has managed environmental permitting and NEPA projects to support the development projects in Native Alaskan communities in Bristol Bay, the Yukon-Kuskokwim Delta, and throughout the Seward Peninsula. For the past seven years, Chris has provided baseline wetland and vegetation studies for public, private, and non-profit organizations. He has extensive experience managing large-scale environmental studies since 2006.

John Morton, P.E. | HDR

John has more than 37 years of experience including 10 years in Alaska. John's background includes a decade working for the Corps of Engineers in their regulatory program. During his career with the Corps of Engineers, John prepared numerous NEPA documents and managed the work of several NEPA third-party contractors in preparing EISs. He is a recognized national expert on the Corps of Engineers' regulatory program, including the 404(b)(1) Guidelines - the Corps of Engineers counterpart NEPA regulations and has a working knowledge of specific Alaska and Federal Agencies tasked with environmental permitting and approvals. John also worked as the permitting and compliance specialist for the Office of Federal Inspections for the Alaska Natural Gas Transportation System. In this role, he identified federal authorizations required, including Federal Energy Regulatory Commission, Corps of Engineers, BLM, and Presidential permits and worked with the project sponsor to obtain required clearances. He also conducted surveys, field data collection, and compliance inspections along the proposed pipeline alignment in Alaska.

Mike Witter | HDR

Mike specializes in wetland and wildlife ecology, and is experienced in conducting natural resource studies in Alaska and the Pacific Northwest. Mike has completed wetland projects for 14 Alaskan projects. Highlights of his Alaskan experience includes having led field crews for two summers to provide wetland delineations for the Northern Rail Extension project, leading field efforts to conduct sensitive plant surveys, non-native plant surveys and wetland delineation. Mike is a Certified Professional Wetland Scientist.

Jodie Anderson | HDR

Jodie is a PhD candidate in soil biogeochemistry from the University of Alaska Fairbanks (UAF); she also has a Master of Arts degree from Brown University. Jodie has extensive teaching experience in Bristol Bay, working as a biology professor at UAF's Bristol Bay campus in Dillingham. She also coordinated the development of a new environmental studies certificate, available through the Bristol Bay campus. Jodie's academic interests have included soil chemistry, permafrost affected soils, and sustainable agriculture (including the use of fish processing by-products as a sustainable alternative to petrochemical fertilizers). Jodie's diverse experience includes tundra rehabilitation on Alaska's North Slope and researching wetlands mitigation opportunities that could offset potential impacts from development.

Attachment 6
Summary Review of Fish Habitat: Flow Dependencies and Methods for Evaluating Flow Alteration Effects

White Paper No. 6
Topic: Assessment of Potential Alterations in Hydrology from Development
Title: Summary Review of Fish Habitat: Flow Dependencies and Methods for Evaluating Flow Alteration Effects
Author: Dudley W. Reiser, Ph.D.

Executive Summary

Determining the amount of water needed to maintain and protect aquatic ecosystems and important fish populations has been an ongoing debate among fish ecologists and water resource users for over 50 years. Fundamentally, there are two different functions that streamflow serves relative to fish and fish habitat: 1) streamflow provides physical space within which fish and other aquatic organisms can live, and 2) streamflow provides the necessary energy and forces to create and maintain physical structures and ecological function in and along the channel including pools, riffles, spawning areas (deposition of new gravels and flushing of fine sediments within existing gravels), off-channel habitats, and riparian communities. Both functions are important relative to promoting stream conditions conducive to salmonid production. Importantly, salmonid habitat requirements vary by life history stage which includes upstream migration, spawning and egg incubation, fry and juvenile rearing, and juvenile/smolt downstream migration. Methods available for assessing instream flow needs vary greatly in the issues addressed, their intended use, their underlying assumptions, and the intensity of the effort required for the application. Most of the general techniques available today have been oriented toward establishing flows to protect fish requirements, i.e., the spatial component of fish habitat rather than habitat formation. However, efforts have also been conducted to determine flushing flow requirements for removal of fines from streambeds, and for channel and riparian maintenance. Four of the more commonly applied methods are described in this paper, including the Tennant/Montana method, Toe-width method, Wetted Perimeter method, and the Instream Flow Incremental Methodology (IFIM)/Physical Habitat Simulation (PHABSIM) model. Three case studies are then summarized that serve to demonstrate just how flow regulation issues have been and can be successfully addressed through the careful design of studies and application of sound scientific methodologies.

1. Introduction

Determining the amount of water needed to maintain and protect aquatic ecosystems and important fish populations has been an ongoing debate amongst fish ecologists and water resource users for over 50 years. With increasing demands for water abstractions and water use, fish biologists in many western states realized that important fishery resources were or already had become jeopardized by lack of sufficient streamflows to maintain population viability. Many states, including Alaska, have long recognized the importance of its fishery resources, both from a recreational and commercial perspective, and as a trust resource for tribal interests. Programs for defining instream flow needs to protect such resources have been implemented in many states (including Alaska, Washington, Oregon, and others) using a variety of methodologies (Reiser et al. 1989; MacDonnell and Rice 1993). Oftentimes the issue of instream flow needs becomes central to the issuance of certain federally mandated licenses or permits. For example, with respect to hydroelectric developments, defining an acceptable, environmentally sound operating and flow release schedule is but one of many requirements that must be met before issuance of a Federal Energy Regulatory Commission (FERC) license to operate the project. The flow release schedule in these cases is usually founded around the protection, mitigation and/or enhancement of fish habitat. Regardless of the specific regulatory mechanism for securing instream flows, the most frequently asked questions when dealing with project specific instream flow issues pertains to flow quantity, i.e., how will changes in flow affect the fish populations and what flows are needed to protect and/or enhance fish habitats?

This paper first summarizes the importance of streamflow on fish and aquatic habitats in streams. It then describes some of the methods and models that are currently used to assess the effects of flow regulation on fish habitats. The paper then briefly describes three case studies where flow regulation was an issue and reviews the specific methods employed in developing instream flow release schedules designed to protect aquatic resources and mitigate for the flow regulation.

2. Streamflow Function

Fundamentally, there are two different functions that streamflow serves relative to fish and fish habitat: 1) streamflow provides physical space within which fish and other aquatic organisms can live, and 2) streamflow provides the necessary energy and forces to create and maintain physical structures and ecological function in and along the channel including pools, riffles, spawning areas (deposition of new gravels and flushing of fine sediments within existing gravels), off-channel habitats, and riparian communities. Both functions are important relative to promoting stream conditions conducive to salmonid production.

Importantly, salmonid habitat requirements vary by life history stage, which includes upstream migration, spawning and egg incubation, fry and juvenile rearing, and juvenile/smolt downstream migration. When these life history stages occur within a given stream is termed “species periodicity,” which depends on the particular species or stock of fish. Figure 1 displays the periodicity chart of different species of fish that are found in the North Fork Koktuli River in Alaska. This figure shows the timing of when adult fish migration, spawning, egg incubation, and fry and juvenile rearing occur in this system. These types of periodicity charts are frequently used in instream flow studies to define biologically sensitive periods of time and serve to focus study efforts.

2.1 Adult Migration

Commencing first with adult migration, it is well known that populations of both salmon and trout exhibit long migrations in streams and rivers to reach their natal spawning streams (Groot and Margolis 1991; Quinn 2005). In the case of salmon and steelhead, (and many stocks of fluvial

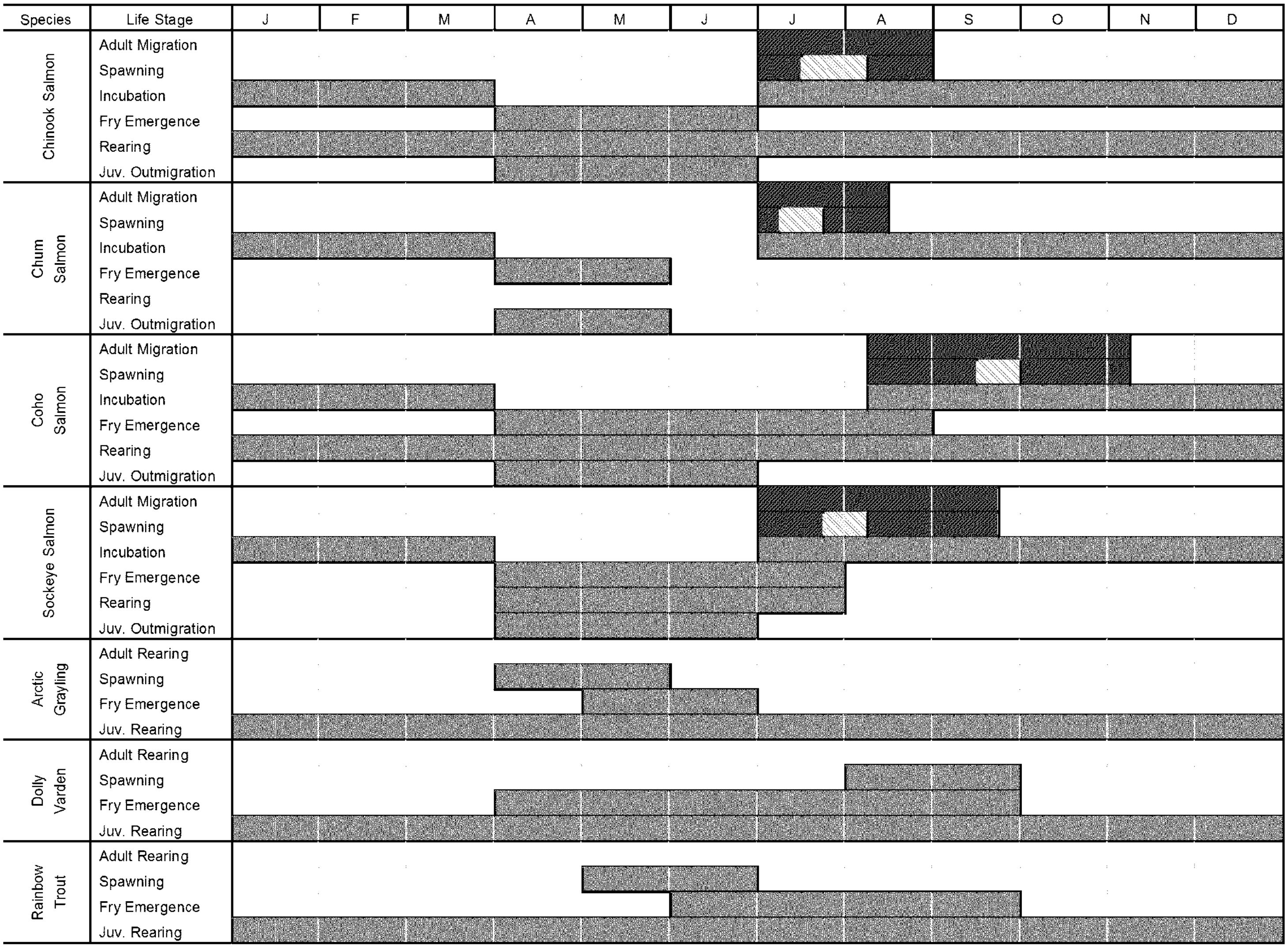

Figure 1 – North Fork Koktuli River, Alaska Periodicity chart.

and adfluvial trout) a strong homing instinct results in the adults seeking and finding the same streams and in many cases the same locations (spawning areas) within those streams in which they were produced (Quinn 2005; Dittman and Quinn 1996; Blair and Quinn 1991; Hasler and Scholz 1983). This homing capability has been shown to be linked to olfactory imprinting[1] that occurs around the time of smoltification and downstream movement of juveniles. Adult salmonids returning to streams to spawn must do so at the proper time and with sufficient energy to complete their life cycle. Successful upstream migration is dependent on a variety of factors, all of which are related to streamflow. These include flow, water temperature, dissolved oxygen, turbidity, and physical barriers.

Without sufficient streamflow in a stream or river, adult fish cannot successfully migrate upstream to spawning areas. The quantity of such flows necessary for passage has been evaluated by a number of investigators who have assessed passage requirements on the basis of the percentage of the average annual flow (Baxter 1961) and on specific water depths and water velocities adult fish are capable of migrating through (Thompson 1972). For trout and salmon, these were defined in terms of minimu m water depths and maximum water velocities and ranged from 0.4 to 0.8 ft, and 4.0 to 8.0 ft/sec respectively (Thompson 1972). These represent minimum depth and maximum velocity criteria and must be evaluated in the context of their application to stream reaches that pose as potential migration barriers, such as shallow riffles. It has also been shown that sufficient water depths and suitable velocities are necessary to allow passage above cascades and falls (achieved via swimming and jumping). Studies have shown that flows that are too low or too high can influence the ability of adult salmonids to migrate upstream to locate suitable spawning areas (Bjornn and Reiser 1991; Powers and Orsborn 1985; Stuart 1964; Thompson 1972).

Physical barriers such as waterfalls, debris jams, beaver dams, and artificial structures (e.g., diversion structures, dams) can delay or prevent upstream migration of adults. Salmon and trout have certain swimming and jumping capabilities that vary by species (Bell 1986; Reiser and Peacock 1985; Powers and Orsborn 1985; others). Importantly, streamflow can directly influence the passage conditions at potential barriers. For example, under conditions of low flow, a particular falls may have a total height that creates conditions greater than the combined jumping and swimming capabilities of salmon and trout, and hence, serves as a barrier to upstream migration. Under higher flow conditions, the height of the falls can be reduced (because of increased water surface elevations in the plunge pool) to levels in which adult passage can occur. Figure 2 illustrates the dependencies of flow on different modes of passage through potential barriers. The important point here is that what appears to be a barrier under one set of conditions may be passable under different flows.

[1] Olfactory imprinting is associated with stream specific odors imparted to the waters that result from watershed characteristics such as soils, flora and fauna.

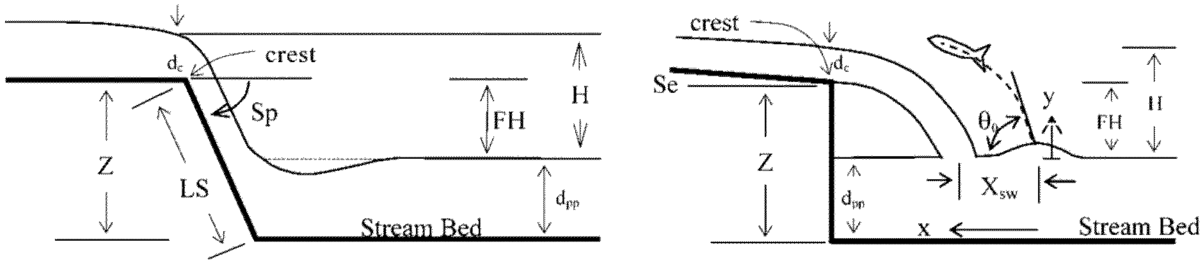

Figure 2 – Schematics of chute-type (left) and falls-type (right) potential barriers (from Reiser et al. 2006, adapted from Powers and Orsborn 1985). Variables are defined as follows: Z is the vertical distance from the bottom of the barrier to the crest of the barrier, H is the vertical distance from the downstream pool water surface to the water surface at the crest, d_c is the water depth at the crest, d_{pp} is the flow depth of the downstream pool, LS is the chute length, S_p is the angle of the chute, S_e is the angle of the bed upstream of a falls, FH is the vertical distance from the downstream water surface elevation to the barrier crest, θ_0 is the initial leaping angle, and X_{sw} is the distance from the location of the impact of the falling water to the standing wave.

As a general precept, the degree to which streamflow conditions may become problematic to upstream migrating adults relates directly to their migration period. Thus, stocks that migrate during the spring under high streamflow conditions (e.g., steelhead) would be less likely to encounter flow related impediments than stocks that migrate later in the year, such as Chinook salmon.

2.2 Spawning

The habitat conditions that meet the reproductive requirements of salmon and trout can arguably be considered as one, if not the most, important condition relative to sustainment of fish populations. The conditions that exist during the period in which eggs are deposited in the gravels, embryos incubate and hatch, and fry subsequently emerge are primary determinants of what is termed "year-class-strength" and the ultimate numbers of fish that may be recruited into the population and return as adults. This year-class-strength can vary widely interannually due to specific combinations of physical and hydraulic characteristics determined largely by stochastic variation in natural climatic conditions. However, anthropogenic impacts related to land-use and water development projects (e.g., irrigation withdrawals, water quality changes, flow regulation below dams, mining, road construction, timbering, etc.) can likewise impact spawning and egg incubation success regardless of climatic variation.

The influence of streamflow on spawning habitat occurs in both a quantitative and qualitative manner. Quantitatively, streamflow plays a direct role in determining the areal extent of habitats that can be used by adult fish for spawning. In general, the amount of spawning habitat in most streams will increase with flow up to a certain point, and then begin to decrease as the velocities over spawning gravels exceeds those used by adults. The magnitude of streamflow also has an influence on the quality of the spawning gravels and on maintaining suitable conditions for incubating eggs within such gravels. This typically occurs as part of the runoff cycle in association with high flows resulting from snowmelt or storm events. These flows typically serve, among other things, to mobilize and transport fine sediments from spawning gravels which is important for increasing gravel permeability and facilitating the interchange of surface and intragravel flows (see Klingeman et al. (eds.)1998; Mosley (ed) 2001)). This interchange is critical for the successful incubation of deposited eggs since the flows result in the transport of oxygen to and removal of metabolic wastes from the embryos. The significance of the interchange of surface with intragravel flows has been demonstrated by Sheridan (1962) and Wells and McNeil (1970). Reiser and White (1981), Wickett (1954) and Chapman et al. (1982) noted relationships between surface flows and intragravel water velocities suggesting that reductions in the former could reduce the latter (Figure 3). The flushing of fine sediments that occurs in conjunction with high runoff in the spring or fall rains serves to increase the quality of the spawning gravels and enhances potential survival to emergence of fry.

2.3 Incubation

Incubation areas are by default selected during the spawning process and are therefore subject to the flow conditions that prevail for several months post-spawning (see Figure 1). This period often includes the winter months when flows are especially low and ice formation and freezing conditions exist. During this period, the eggs develop and hatch, alevins absorb yolk sacs, and fry emerge from the gravels. Low flow conditions occurring in the winter can result in the dewatering and intragravel freezing of redds and high egg and alevin mortality.

The intragravel environment that contains the incubating embryos is part of what is termed the hyporheic zone, which can generally be defined as the saturated area beneath the streambed that contains a combination of surface and groundwater flow (Edwards 1999; Harvey and Wagner 2000). To a large extent, the development and survival of embryos is highly dependent on the environmental conditions existing within this zone (Malcolm et al. 2008), including water temperature, dissolved oxygen concentrations, and other water quality constituents, as well as rates of flow. Thus, streamflows sufficient to maintain the interchange of surface and groundwater flows within the hyporheic zone are important for the successful incubation of deposited eggs, because the flows result in the transport of oxygen to and removal of metabolic wastes from the embryos. The significance of the interchange (i.e., downwelling) of surface with intragravel flows has been demonstrated by Sheridan (1962) and Wells and McNeil (1970). Chapman et al. (1982), Reiser and White (1981), and Wickett (1954) noted relationships between surface flows and intragravel water velocities, suggesting that reductions in the former could reduce the latter. Areas of groundwater upwelling are also important and are often sought-out for spawning, especially by certai n species of anadromous salmonids — including sockeye (Foerster 1968; Lorenz and Eiler 1989) and chum salmon (Helle 1980; Groot and Margolis 1991). These areas may be formed directly from groundwater recharge or from surface flow recharge from upslope gravel areas that discharge downslope. These areas generally provide flow constancy and stable water temperatures that are conducive to embryo development.

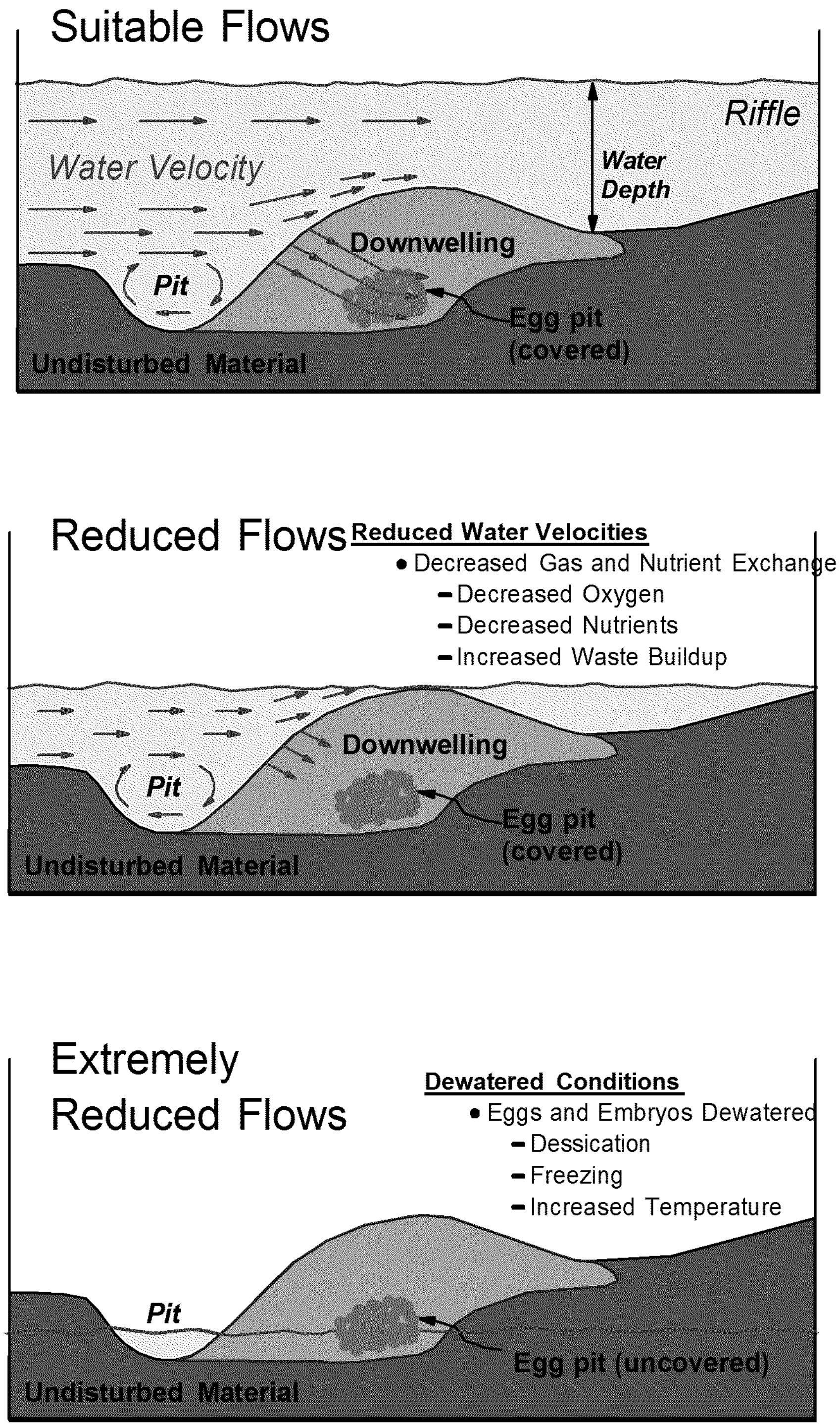

Figure 3 – Conceptual diagram of salmonid spawning nests illustrating generalized effects of streamflow reductions on the intragravel environment.

2.4 Fry and Juvenile Rearing

Both anadromous and non-anadromous salmonid fry and juveniles rear in freshwater; anadromous salmonids for varying periods of time before out-migrating to the ocean (saltwater) (Quinn 2005; Groot and Margolis 1991). The habitats that constitute rearing areas are diverse and include both main channel and off-channel areas. As in spawning, streamflow is the primary determinant of a number of specific factors that contribute to defining the quality and quantity of suitable rearing habitat. These factors include, but are not limited to: water depth, water velocity, pool volume, water temperature, dissolved oxygen, substrate quality, and in many instances, physical structure and habitat such as large woody debris. Relevant to the first two factors, streamflow has a direct influence on the distribution and quantity of water depths and associated velocities that are most often utilized by fry and juvenile salmonids. Chapman (1966) considered velocity to be perhaps the most important of the two factors, noting that without suitable velocities, no fish will be present. Studies have shown that fry of salmon and trout typically utilize velocities less than 0.3 feet per second (Chapman and Bjornn 1969; Everest and Chapman 1972; Griffith 1972). As fish grow, they become stronger and are often associated with higher water velocities (Smith and Li 1983). Shifts in velocity usage by fish have been observed seasonally, presumably in response to water temperature changes. The shifts are generally from higher velocities in the summer feeding periods to lower velocities during the winter holding periods (Chisholm et al. 1987; Tschaplinski and Hartman 1983).

Water depths used by fry and juveniles can be quite variable, depending on the factors associated with such depths (e.g., substrates, cover, food, velocity, predator density). Newly hatched fry often utilize the extreme edge habitats of a stream where velocities are low and there are few predators. As fish grow, they are capable of using deeper waters with limits of use generally related to some other interrelated parameter—such as water velocity. Bjornn and Reiser (1991) noted that some salmonids are found in higher densities in pools than other habitat types as a result of space availability. This suggests other factors may be acting to regulate such densities; e.g., presence of large woody debris, undercut banks, or overhanging vegetation.

Because fry and juvenile fish tend to use slower velocities than adults (in conjunction with spawning), the relationships of main channel rearing habitat to flow tend to show a pattern suggesting that lower flows provide more habitat than higher flows. However, this can be misleading since juvenile fish are often associated only with edge habitats, for which conventional flow assessment methods do not account for. In addition, many juvenile salmon utilize off-channel habitat areas so that the real issue relative to juvenile habitat is one of maintaining connectivity between the mainstem flows with off-channel areas. Figure 4 provides a conceptual representation of how juvenile rearing habitat is influenced under different flow conditions.

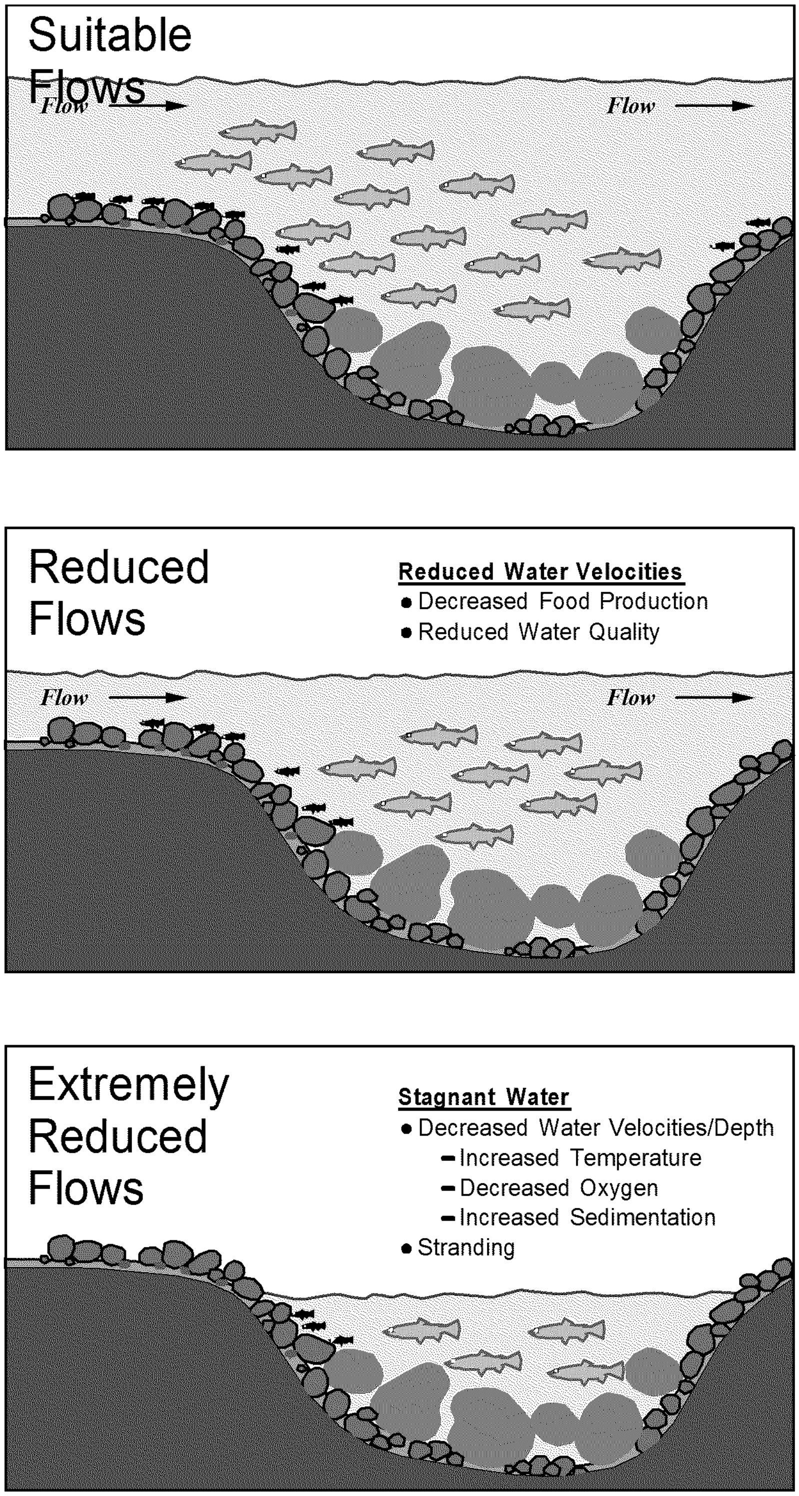

Figure 4 – Conceptual diagram of salmonid rearing habitat illustrating concept of carrying capacity as it relates to streamflow quantity.

2.5 Downstream Migration

A period during which juvenile fish begin a directed movement downstream is a characteristic of salmon and stocks of fluvial and adfluvial trout and char. In the case of salmon, this process is preceded and triggered by physiological changes occurring in the fish that are known as smoltification, a process that is essentially readying the fish for transition to salt water. For non-anadromous fish, physiological changes may not be evident, but there is nevertheless a directed movement downstream.

In many streams in the northwest and Alaska, the timing of the seaward migration of salmon has apparently evolved in concert with the cycle of runoff from adjoining mountains and hills, and has done so as a means to increase the survival rates of the fish. The outmigration typically occurs during the spring in the months of March-May (see Figure 1). As noted earlier, the high flows that occur during this period likely benefit the survival of smolts in both a direct and indirect manner. The high flows allow the smolts to conserve energy since most of the work is done by the stream in the form of kinetic energy. This can have a direct influence on the smolt travel time and its ultimate condition when it reaches the ocean and its ability to survive the transition to saltwater. The increased turbidities that are generally associated with high flows also afford the smolts protection from predators during downstream passage. These and other benefits associated with high flows during passage can affect the travel time of smolt, as has been demonstrated by a number of state and federal agency personnel (Buettner 1991; Buettner and Brimmer 1993; Kiefer and Forster 1991; ISG 1996).

In regulated streams where even high flows are contained and controlled (e.g., dam construction-creation of reservoirs; transbasin diversions of water; large irrigation withdrawals, etc.), the downstream passage of smolts and juveniles can be adversely affected. In cases where a dam has been constructed and a large reservoir formed, the smolts may have a difficult time locating velocity cues to guide them down through the reservoir. This increases their passage time and renders them more susceptible to predation. In addition, too long of a delay can reduce or eliminate their instinct to migrate and the fish may simply cease migration and take up residency (i.e., residualize).

2.6 Channel and Riparian Forming Flows, and Flows and Ice Formation

Natural runoff processes that annually and seasonally provide high flows within the stream channel are important for transporting sediments (from riffles and pools), maintaining channel conveyance, creating and maintaining physical habitat structure in the channel, and providing connectivity with the riparian zone and vegetation thereof. Poff et al. (1997), Locke et al. (2008) and others have summarized the importance of the natural flow regime on a variety of ecosystem components and advocated that flow-based stream restoration focus on goals designed to promote a more natural regime in rivers. In regulated systems, the derivation of what are termed channel or habitat maintenance flows has been used as a means to mimic these processes and maintain channel form and function (Schmidt and Potyondy 2004).

Flood flows that exceed channel capacity and spill-over onto the adjoining flood plain are considered a required component for the maintenance of riparian ecosystem functions (Poff et al. 1997; Gregory et al. 1991; Hill and Platts 1991). These flows serve, among other things, to recharge alluvial aquifers, provide sites for seedling establishment, transport and deposit seeds on the floodplain, and replenish nutrients in floodplain soils (Chapin et al. 2002). Sufficient in-channel flows are often also important for maintaining the alluvial aquifer within or near the rooting zone of riparian plants through the growing season. Riparian species are typically hydrophytic plants (i.e., occur in soils saturated or inundated for extended periods during the growing season), and require relatively high levels of soil moisture throughout the growing season, in contrast to adjacent upland plant communities. As a result of the various flow needs of the riparian zone, reduction in the frequency and magnitude of flood flows or reduced in-channel flows can cause the riparian zone to become smaller (both in width and in stature), less diverse, or even eliminated (Figure 5). These effects in turn can have negative consequences in fish habitat due to increases in water temperature, reductions in cover (e.g., wood recruitment) and channel complexity, and lower or altered trophic inputs (e.g., terrestrial insect input). As a result, more water resource allocation studies are assessing the flow requirements for protecting riparian ecosystem functions (Chapin et al. 2000; Whiting 1998; Stromberg and Patten 1991; Rood et al. 1995; Scott et al. 1997).

Streamflow also plays a role in the location, timing, magnitude, and duration of ice formation, and in the process of ice decay, breakup and ice-out. Fish habitats can be dramatically affected by ice formation and breakup which can serve as a limiting factor on overwintering survival of fish (Brown et al. 2011). Flow regulation can alter the normal patterns of ice development and decay thereby modifying its role in channel formation and how it influences fish habitats.

3. Instream Flow Methods for Evaluating Flow Regulation Effects

Methods available for assessing instream flow needs vary greatly in the issues addressed, their intended use, their underlying assumptions, and the intensity of the effort required for the application. Many techniques, ranging from those designed for localized site or specific applications to those with more general utility have been used. Most of the general techniques available today have been oriented toward establishing flows to protect fish requirements, i.e., the spatial component of fish habitat rather than habitat formation. However, efforts have also been conducted to determine flushing flow requirements for removal of fines from streambeds (Reiser et al. 1989) and for channel (McNamara et al. 2000) and riparian maintenance flows (Chapin et al. 2000; Whiting 1998; Schmidt and Potyondy 2004).

Of the habitat methods available, the Instream Flow Incremental Methodology (IFIM) (Bovee 1982; Stalnaker et al. 1995) and its associated computer programs – Physical Habitat Simulation (PHABSIM) are the most widely used in North America (Reiser et al. 1989). Other methods commonly applied in the western states include the Tennant or Montana method (developed by D. Tennant in Montana) (Tennant 1976); toe-width (developed for western Washington streams) (Swift 1976; 1979), and the wetted perimeter method (Nelson 1980). Another hydrologically based method, the Indicators of Hydrologic Alteration/Range of Variability (IHA/RVA) has been increasingly applied in a number of western streams (Richter et al. 1996). These methods are briefly described below. Although there are additional methods, this paper provides an overview of four methods most commonly used in the western states on streams containing salmonid populations: Tennant/Montana, Toe-width, Wetted-Perimeter, and IFIM/PHABSIM.

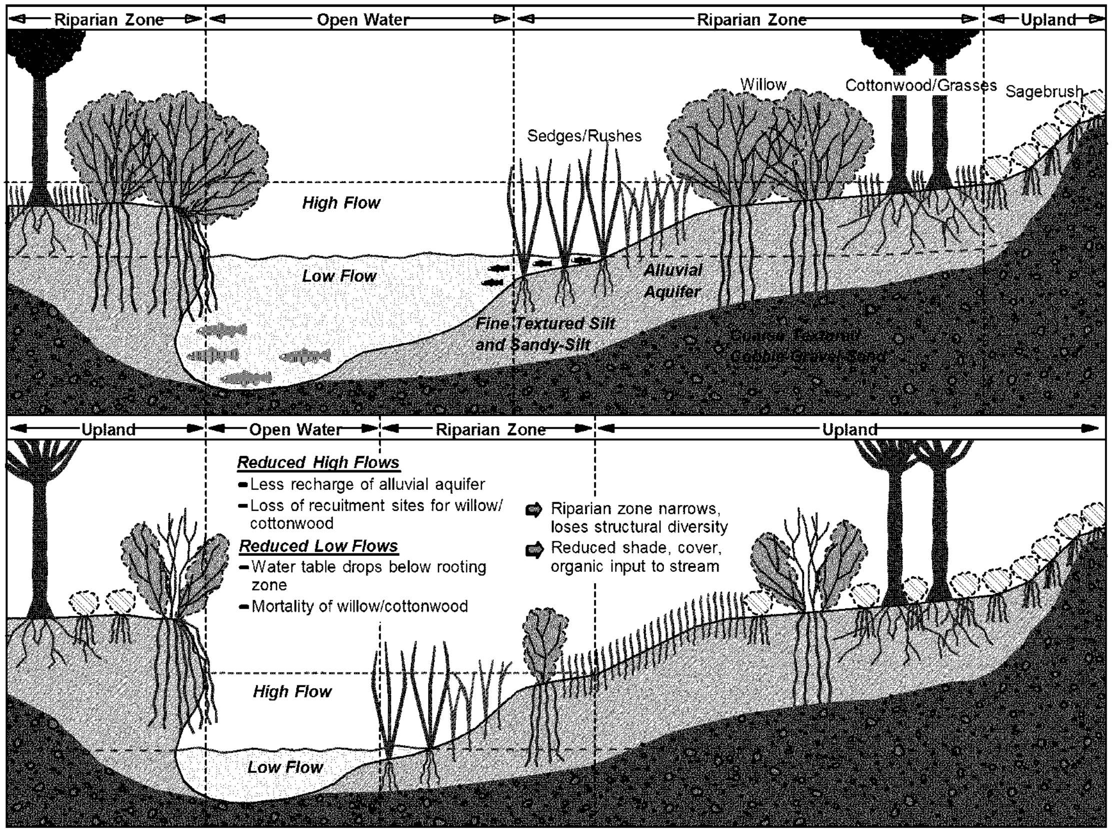

Figure 5 – Relationship of high and low flows to riparian plants and soils under natural flow regime (above) and reduced flow regime (below) showing potential effects of reduced flows.

3.1 Tennant/Montana Method

The Montana Method was developed by Donald Tennant in 1976 and is still one of the most widely applied methods for establishing instream flows for broad scale studies and regional planning efforts. The method is hydrologically based and is founded on the premise that the flow of a stream is a composite manifestation of characteristics such as drainage area, geomorphology, climate, vegetation cover, and land use. It has been successfully tested in court, requires minimal expenditures of resources and can be used with limited or extensive hydrological and fishery data. The Montana Method is considered one of the simplest techniques for selecting or qualitatively evaluating instream flows for fish. In general, the method relies on eight flow classifications established by Tennant after analyzing a series of field measurements and observations. Those classifications have been modified by a number of investigators (e.g., Tessman (1980); Estes 1984, 1996) to afford additional protection to the fishery resource during different seasons. The eight flow classifications as established by Tennant (1976), along with seasonal modifications are provided in Table 1. Each classification is assigned a percentage or percentage range of the average annual flow (QAA). The percentages are then applied to specific times of year with the year divided into two six-month periods, April through September and October through March.

The recommended base flow regimes (QAA) can be obtained from existing flow records and is calculated by averaging the mean daily flow for the year. It can also be estimated using regional hydrological models. Seven of the Tennant classifications characterize habitat quality for fish and the eighth provides for a flushing flow. The percentage of QAA for habitat quality range from less than 10% (Severe Degradation) to 60% - 100% (Optimal Range). The flushing flow classification represents twice the average annual flow.

Table 1 – Instream flow regimes for fish habitat (Tennant, 1976).

Narrative Descriptions of Flows	Recommended Base Flow Regimes (QAA)	
	Oct. – Mar.	Apr.-Sept.
Flushing Flow	200%	200%
Optimal Range	60 – 100%	60 – 100%
Outstanding	40%	60%
Excellent	30%	50%
Good	20%	40%
Fair	10%	30%
Poor or Minimum	10%	10%
Severe Degradation	10%	10%

3.2 Toe Width Method

The Toe-Width Method was developed by the Washington Department of Fish and Wildlife and the U.S. Geological Service (USGS) (Swift 1976; 1979) in the 1970s at the request of the state legislature in Washington in response to the need to determine minimum instream flows for fish. In a joint effort, the state and USGS collected water depth and velocity data from some 336 transects over a nine-year period at 8 to 10 different flow levels. This information was combined with criteria for the needed spawning and rearing depth and velocities for each fish species and life stage to calculate the square feet of habitat at each of the measured flows. These points of habitat quantity at different flows were connected to create a fish habitat versus streamflow relationship. Next, fish habitat relationships were compared to many different variables in the watershed to determine if there were any correlations that could be used to predict the flows necessary for protection of spawning and rearing habitat. The toe-width was the only variable found to have a high correlation with flow necessary to protect spawning and rearing habitat. The toe-width is the distance from the toe of one streambank to the toe of the other streambank across the stream channel. The toe-width method produces a strong correlation between an easily measured stream variable (the toe-width) and the empirically determined discharge that produces maximum and sustained spawning and rearing habitat. Its use has been generally limited to streams in Washington.

3.3 Wetted Perimeter

Since discharge variables are not necessarily correlated with any biologically beneficial features in streams, several investigators turned instead to simple cross sectional hydraulic or structural measurements as a way to approximate fish habitat. With wetted perimeter (the distance from water's edge to water's edge along the bottom of the channel), the variable changes with flow, and a variety of biological benefits can be ascribed to increasing the amount of wetted perimeter. The method generally results in a "minimum flow" recommendation that would be in effect year round, rather than a temporally variable set of flows as developed via PHABSIM. Typically with this method, the analyst selects a critical area (typically a riffle) as an index of habitat for the rest of the stream. When a riffle is used as the area, the assumption is that a minimum flow satisfies the needs for food production, fish passage, and spawning. The usual procedure is to choose the break or "inflection point" in the streams wetted perimeter versus discharge relation as a surrogate for minimally acceptable habitat (See Figure 6). The inflection point represents that flow below which the rate of wetted perimeter declines dramatically and hence represents the minimum flow.

3.4 IFIM/PHABSIM

The PHABSIM is the most common tool used for evaluating the incremental change in habitat quantity and quality as a result of varying stream flows. The use of PHABSIM allows agency and stakeholder groups to incrementally evaluate the resource tradeoffs of various instream flow scenarios. The PHABSIM system, which is nested within the umbrella IFIM, is the hydraulic modeling and habitat analysis component of a comprehensive set of microcomputer based models used to simulate habitat conditions in rivers and streams for various species and life stages of fish over a range of discharge conditions (Bovee 1982; Stalnaker et al. 1995).

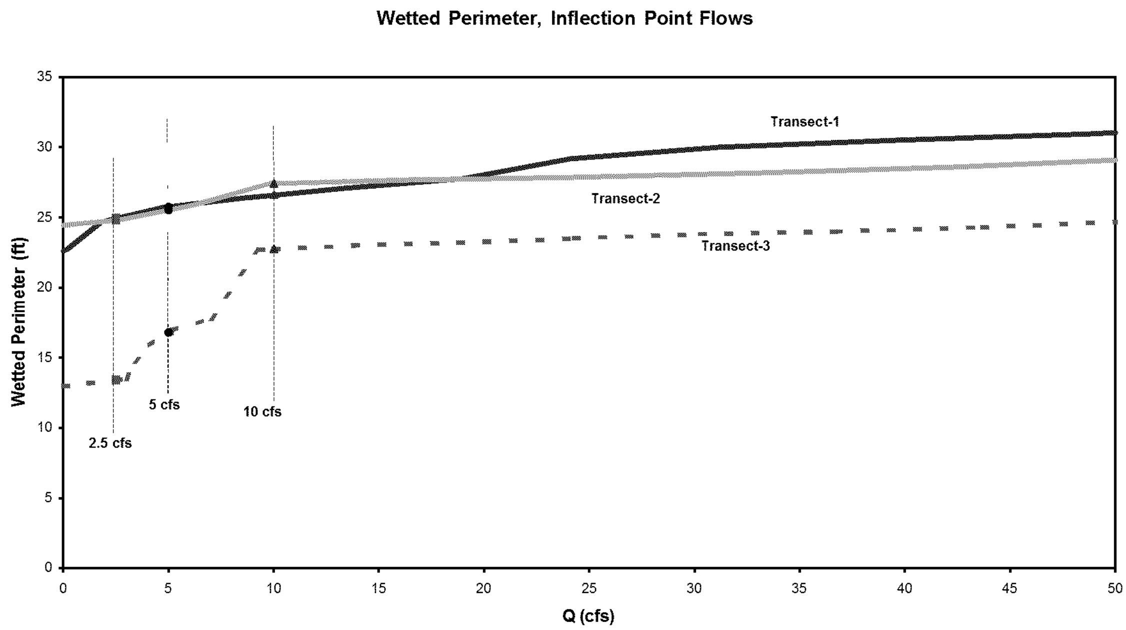

Figure 6 – Example of wetted perimeter versus flow relationships.

The basic application of PHABSIM involves selecting a representative section of the stream or river, typical of the river's morphology and habitat conditions. Hydraulic and physical characteristics (depth and velocity, substrate composition) are then measured at a number of points across transects placed perpendicular to the flow, within different habitat types (pool, runs, and riffles). The method assumes that these three parameters (i.e., depth, velocity, and substrate) direct or determine the suitability of any particular segment of the stream channel for a specific species and life stage of fish. The suitability of different combinations of depth, velocity, and substrate is defined via development and application of a set of Habitat Suitability Criteria (HSC) curves that define species and life stage specific use of different depths, velocities and substrate mixtures. When the HSC curves are integrated with the hydraulic and habitat models, the resulting output is of a form that allows graphical depiction of habitat (defined as Weighted Usable Area – WUA) versus flow, an example of which is shown in Figure 7. Such curves will be provided for each species and life history stage for which HSI data exist. For spawning, there is generally a consistent three stage pattern apparent in the relationship consisting of: 1) an initial increase in habitat with increasing flows as more spawning area is wetted and combinations of water depth and velocity remain suitable; 2) a leveling off of habitat as flows continue to increase; and 3) a decrease in spawning habitat as flows continue to increase as water depths and velocities begin to exceed those utilized by salmon and trout. The most current versions of PHABSIM provide a su ite of analytical tools (time series, effective habitat, etc.) that can be used for further evaluating these relationships.

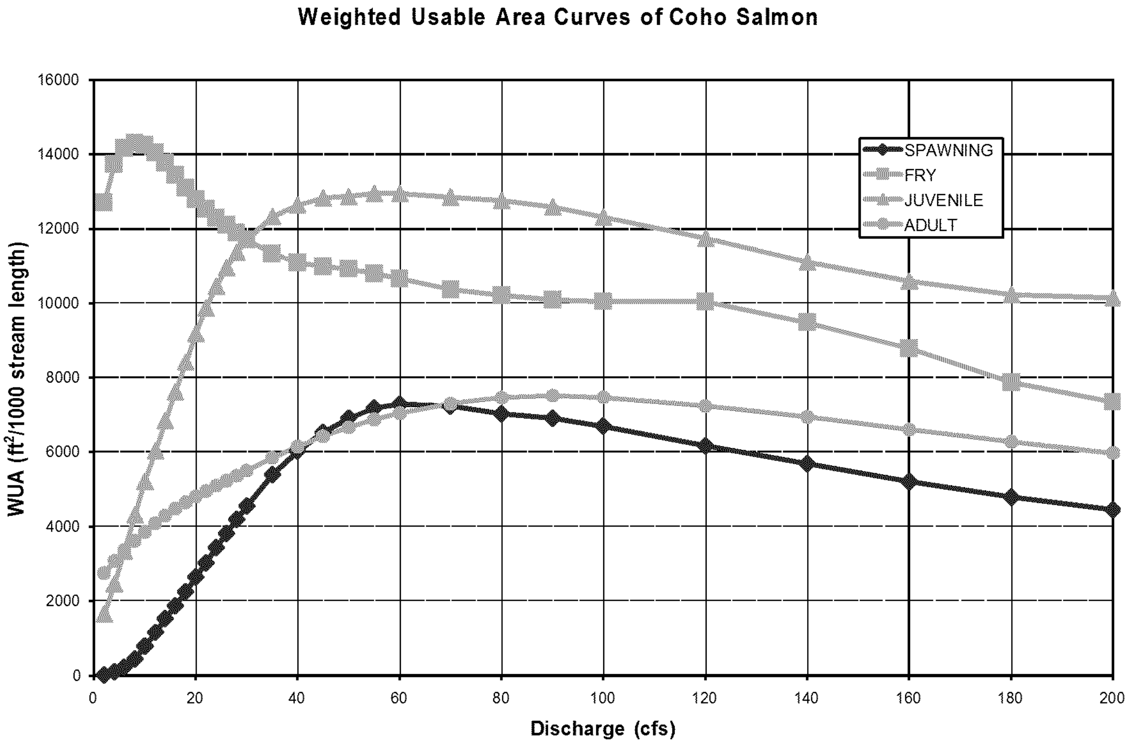

Figure 7 – Example of PHABSIM output showing habitat vs. flow relationships for spawning, fry, juvenile, and adult coho salmon.

PHABSIM has been used world-wide on a variety of projects where the nexus of stream flow and fish habitat occurs. These have included, perhaps most commonly, water resource development projects such as those involving hydroelectric developments and other water supply projects (municipal, agricultural) where the issue is understanding how flow regulation may influence fish habitats. In these projects, operations models are often linked with PHABSIM analysis as a means to evaluate different operational scenarios, assess impacts, and evaluate tradeoffs between e.g., power production and fish habitat. Table 2 provides examples of projects where PHABSIM has been applied to evaluate flow related effects on fish habitats, quantify aquatic habitat, and derive mitigation measures.

In Alaska, this type of application of PHABSIM has occurred on a number of hydroelectric projects including the Terror River, Whitman Lake, Connell Lake, Cooper Lake and several other projects (Table 2). In a 1991 study prepared by the U.S. Department of Energy (Sale et al. 1991), information on specific mitigation practices was obtained from 280 hydropower projects that were identified as having mitigation requirements of interest. Of all the projects receiving FERC licenses or license exemptions since 1980, instream flow requirements are the most common mitigation requirement (Sale et al. 1991). Of the established and documented methods used to determine requirements for instream flows, the most frequently applied was the Instream Flow Incremental Methodology (IFIM) and the PHABSIM programs (Sale et al.

1991). In addition, IFIM was the most frequently identified assessment methodology by state agencies (Annear et al. 2004; Reiser et al. 1989).

PHABSIM has also been used on mining related projects, including: in Alaska the Red Dog Mine near Kotzebue and the Quartz Hill Project near Ketchikan where it was applied in evaluating the effects of potential flow regulation due to proposed mine operations on project streams; in Idaho, where it was used for quantifying habitats under different flow conditions as a means to estimate potential fish production related to mitigation and enhancement measures (e.g., Coeur d'Alene basin, Yankee Fork, East Fork Salmon River, Panther Creek; Table 2); and in Montana where it was used to evaluate non-mining related effects of flow regulation on fish production at a mine Superfund site. A brief overview of several case studies on how PHABSIM was used to evaluate flow regulation effects and develop habitat mitigation strategies to effectively address impacts associated with development projects are discussed in the next section.

4. INSTREAM FLOW CASE STUDIES

There have been literally hundreds if not thousands of studies that have focused on addressing instream flow needs for fish and aquatic biota. Many of these have been conducted in conjunction with water rights adjudication proceedings, hydroelectric licensing and relicensing activities, and in association with federal and state permitting for flow diversion and regulation. In 2008, the Instream Flow Council (IFC) reviewed and described eight case studies that provided real-world examples of how instream flow issues have been addressed under different geographic settings and for different purposes (Locke et al. 2008). The following subsections summarize three of these case studies and serve to demonstrate just how flow regulation issues have been and can be successfully addressed through application of appropriate instream flow methods.

4.1 Terror Lake Hydroelectric Project, Alaska

The Terror Lake Hydroelectric Project, located on Kodiak Island, Alaska provides an excellent example of "how an instream flow prescription can be designed to achieve no net loss of salmonid habitat" (Locke et al. 2008). The project's stated goal was to allow flow diversions only if it could be shown that no significant impact would likely occur to salmon utilization in the river. A series of ambitious studies were undertaken that considered the habitat needs of three species of Pacific salmon, as well as hydrology, water temperature, sediment transport and channel morphology. The focus of the fish related studies was on assessing the needs for salmon spawning, egg incubation, and juvenile rearing, which, as noted in section 2 of this paper are all flow dependent. These studies were done with the recognition that the Alaska Department of Fish and Game had filed for instream flow water reservations to support salmon spawning and incubation for the river, and that the project location aligned with the Kodiak National Wildlife Refuge, which carries with it a federal reserved water right to ensure that "the water quality and necessary water quantity" are maintained to protect fish and wildlife populations and habitats.

Table 2 – Examples of projects where PHABSIM has been applied

Name	Location	Description of Project	Recommended Mitigation Measures	Evaluation Methodology Used	Source
Mine Related Projects					
Quartz Hill (Wilson River and Tunnel Creek)	Misty Fjords National Monument, Southeast Alaska	Evaluation of water withdrawal for a Molybdenum Mine development	Minimum instream flow recommendations	IFIM/PHABSIM used to develop minimum instream flows	Lyons 1985
Panther Creek	East central Idaho	Habitat rehabilitation of Panther Creek watershed from toxic mine effluent	Habitat enhancement	IFIM/PHABSIM used to evaluate habitat enhancement alternatives	Reiser 1986
East Fork Salmon River	Idaho	Identification and remediation of habitat problems in the basin as a result of grazing, mining, and dams	Stream corridor fencing Bank erosion protection Riparian zone revegetation	IFIM/PHABSIM used to estimate changes in habitat and fish production potential before and after implementation of enhancement alternatives	EA 1988
Yankee Fork Salmon River	Idaho	Identification of habitat enhancement needed as a result of mining and hydropower development	Development of off-channel rearing habitat; construction of instream enhancement structures to create in-channel habitat; stabilization of stream banks and erosion	IFIM/PHABSIM used to estimate existing and with alternative habitat and smolt production capacity	Reiser and Ramey 1987
Prosperity Gold-Copper Project	South central British Columbia	Gold and copper mine development	Development of a fish compensation plan which includes off-site habitat enhancement projects needed as a result of flow diversions and other project impacts	Wetted width	Taseko 2009

Table 2 – Examples of projects where PHABSIM has been applied (continued).

Name	Location	Description of Project	Recommended Mitigation Measures	Evaluation Methodology Used	Source
Hydropower Projects					
Terror River	Kodiak Island, Alaska	Diversion of water from the Terror River into a hydropower facility that releases water into the Kizhuyak River	Funding for future scientific studies; establishment of replacement lands for lost habitat; minimum instream flows	IFIM/PHABISM used to develop minimum instream flows	Olive and Lamb 1984, Locke et al. 2008
Cooper Lake	Kenai Peninsula Borough, south-central Alaska	Diversion of outflow from Cooper Lake into a hydropower facility which releases into the Kenai Lake	Minimum instream flows for releases from Cooper Lake into Cooper Creek; diversion of water from Stetson Creek into Cooper Lake	IFIM/PHABSIM used to develop minimum instream flows	Kent and Morsell 2004
Tyee Lake	Southeast Alaska	Diversion of water from Tyee Lake	Habitat enhancement	Studies quantifying fish use	Thrall and Morsell 2001
Bradley Lake	South central Alaska	Diversion of flow via a lake tap in Bradley Lake to a hydropower facility.	Minimum instream flows	IFIM/PHABSIM used to develop minimum instream flows	Thrall and Morsell 2001
Falls Creek	Gustavas, Alaska	Run-of-river hydroelectric facility which diverts water from Falls Creek through a bypass channel	Minimum instream flows; land exchange	IFIM/PHABSIM used to develop minimum instream flows	R2 Resource Consultants, Inc. 2000

The primary method used for evaluating fish habitat needs was PHABSIM. This was supplemented with use of a water temperature model as a means to assess both habitat and temperature versus flow relationships. Results from these analyses were linked with hydrology data and a time series evaluation was completed. This resulted in development of a seasonal flow regime that was intended to maintain all salmon life stage habitat values at, or near and often above pre-project levels.

The flow regime was subsequently implemented and six years of post-project monitoring completed. Monitoring results indicated that the construction and operation of the project did not have any adverse effects on salmon production. In fact, post-project salmon returns tended to be higher than pre-project levels. Salmon were also documented spawning further upstream than under pre-project conditions. As a result, there were no changes to the instream flow regime proposed as a result of the post-project monitoring. Reasons cited for the success of this project included the project and regulatory team that was involved, the physical setting, and importantly, the application of objective science. This study clearly demonstrates that when the needs of fish are carefully considered and factored into the development and operation of a project, project effects can be avoided and conditions even enhanced over those occurring pre-project.

4.2 Cedar River, Washington - Instream Flow Agreement and Habitat Conservation Plan

The Cedar River is located in western Washington and like many urbanized systems, has been subjected to a long history of engineering actions designed to promote development. Originally a tributary to the Duwamish River system, the Cedar was re-routed to drain directly into Lake Washington as a means to facilitate navigation between saltwater in Puget Sound and freshwater streams via a series of locks at the western end of Lake Washington. The Cedar River maintains populations of sockeye salmon and historically likely supported runs of Chinook and coho. In 1979, the State of Washington adopted instream flows for the Cedar River, although the quantification methods were questioned by several stakeholders. With the listing of Chinook salmon and bull trout under the federal Endangered Species Act (ESA), the City of Seattle took a proactive approach toward improving overall conditions in the Cedar River to protect these species, as well as other fish species of concern. An Instream Flow Committee was formed in 1986 consisting of members from agencies and tribes. This committee focused on development and implementation of a series of studies designed, in part, to evaluate the instream flow needs of the above species.

Instream flow studies were conducted using PHABSIM and included development of HSC curves, determination of habitat-flow relationships, and completion of a habitat time series analysis (Locke et al. 2008). Again, the focus of these studies was on evaluating and understanding the flow requirements of the different species and life stages of fish. Further studies involved an effective and cumulative spawning area analysis, as well as studies focused on smolt outmigration. A flow management proposal was developed by the Washington Department of Fish and Wildlife that included weekly flow recommendations to protect the species and life stages of interest. In 2000, an Instream Flow Agreement and Habitat Conservation Plan were officially signed and implemented. These agreements have resulted in the implementation of numerous flow and non-flow prescriptions designed to protect, mitigate for, and/or enhance habitat conditions of the fish species. An important element of these plans was the development and initiation of an extensive monitoring and research program and adaptive management process designed to provide a feedback loop that allows for modification to the flow actions based on monitoring results.

This case study again demonstrates that even in complex situations, resource protection can be achieved when stakeholders collaborate and utilize sound scientific methods to address problems.

4.3 Trinity River, California – Restoration Program

The Trinity River is located in California and has been subjected to various water resource developments since the 1930s. These have all focused around the diversion of flows as part of California's Central Valley Project for irrigation purposes, but have also included construction of several dams (Lewiston Dam, Whiskeytown Dam) and a hydroelectric facility on Lewiston Dam. The river supports steelhead trout as well as coho and Chinook salmon but with the construction of the diversion systems, about 110 miles of upper basin watershed that contained spawning, rearing, and holding habitats were blocked (Locke et al. 2008). This led to the subsequent decline of salmon and steelhead populations leading to the formation of the Trinity River Basin Fish and Wildlife Task Force in 1971. The focus of the task force was to halt degradation of fish and wildlife populations and to formulate a long term restoration plan for the river.

Stream flow releases were central to the restoration program and a series of early studies conducted by the California Department of Fish and Game in the early 1970s derived a set of flow recommendations that attempted to mimic natural snowmelt conditions. This led to the preparation of an Environmental Impact Statement and subsequent enactment of legislation that provided funding and technical support to the restoration efforts. In 1998, the U.S. Fish and Wildlife Service and Hoopa Valley Tribe prepared a summary report of all previous studies for the project that concluded that restoration actions would require three elements – modified flow regime, reconfigured channel, and a sediment management strategy. The modified flow issue was addressed via completion of a number of studies that utilized the IFIM/PHABSIM methods that focused on deriving habitat flow relationships for different life stages of Chinook and coho. Separate studies were completed to address fluvial geomorphology and sediment transport issues that included derivation of sediment flushing flows. In addition, water temperature modeling was conducted using the Stream Temperature Network Model (SNTEMP).

The results of the different studies were integrated into a salmon production model (termed SALMOD) that provided guidance in identifying specific flow release objectives. Coupled with results from the channel and sediment studies and temperature modeling, three flow related objectives were identified: 1) flow releases should provide suitable spawning and rearing habitats; 2) flow release should mimic the timing of natural runoff processes; and 3) flow releases should provide temperature objectives for holding and spawning adults. These studies culminated in a Record of Decision for the Trinity River Restoration Program in 2000. One of the key actions specified in the Record of Decision was the provision of variable instream flows based on forecasted hydrology for protection of the fish resources. This program has been operating since 2000 and has included a comprehensive monitoring and adaptive management program that provides for feedback and flexibility in how flows are managed in any given year. The program also includes a number of channel rehabilitation projects designed to improve channel conditions and re-establish connections with functional floodplains that can serve as high water refuge habitats and juvenile rearing areas for fry and juvenile salmonids.

Overall, the Trinity River case study is another example of complex water resource issues being addressed through: 1) careful study and evaluation; 2) application of sound science and engineering practices to develop implementable solutions; and 3) development and implementation of a comprehensive monitoring and adaptive management program.

5. SUMMARY

This paper has shown the importance of flow to the functionality of various fish life stages and that flow regulation can have significant biological impacts on fish and aquatic resources. The degree of effect of course depends on a number of factors, including the type, magnitude, timing, and duration of the flow regulation. Defining the effects of flow alteration on fish and fish habitats has been the focus of instream flow related research for more than 50 years. Fortunately, during this time a variety of methods and models (some of the more commonly applied methods are described in this paper) have been developed that can help to understand and define these effects and provide guidance in formulating instream flow prescriptions designed to protect, mitigate for and even enhance habitat conditions. The case studies described herein provide real-world examples of where and how the impacts associated with flow regulation on fish habitats have been successfully addressed. In all cases, the key ingredients leading to success included the careful design of studies and application of sound scientific methodologies for identifying and quantifying impacts and deriving appropriate instream flow measures.

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Attachment 7
Toutle River Recovery Post Mount St. Helen Eruption

White Paper No. 7
Topic: Resiliency in natural systems
Title: Toutle River Recovery Post Mount St. Helen Eruption
Authors: Jude Simon, Danielle Evenson, MaryLouise Keefe, and Tim Sullivan

Executive Summary

The eruption of Mount St Helens on May 18, 1980 decimated the surrounding landscape with pyroclastic flows, mud flows, debris avalanches, hot gases and ash fall. The Toutle River subbasin was particularly heavily impacted by mudflows and a massive debris torrent. While much of the habitat in the Toutle River was destroyed, some localized, less degraded areas continued to support aquatic life. The eruption provided a unique opportunity to study the Toutle River's response to major environmental disturbance. In doing so, we also gain insight into the components and processes inherent to natural aquatic systems that support persistence in an unpredictable environment. The objectives of this paper are to describe the response of the Toutle River system and identify key factors that contributed to fish population and habitat recovery.

Within one year post-eruption, aquatic habitats and fish populations began moving toward recovery. Many fish populations recovered in the Toutle River system more quickly than managers and biologists thought possible. The post-eruption rebound of both stream-dwelling and lake-dwelling fish populations appears to have been driven by complex biological and ecological processes that relied upon fish life history variations, habitat refugia, aquatic habitat connectivity, increased primary productivity, surviving fish populations and colonists, food abundance, and the absence of competition and predation. These processes, as well as management practices such as harvest reductions and fish stocking, have also played a role in shaping the recovery of fish populations.

The Toutle River system historically supported populations of several salmonid species that are currently listed as threatened under the federal Endangered Species Act including winter steelhead (*Oncorhynchus mykiss*), coho salmon *(O. kisutch)*, spring and fall Chinook salmon (*O. tshawytscha*), and chum salmon (*O. keta*). These salmonids possess diverse life history attributes that favor survival in unpredictable environments including the high mobility of juvenile and adults across habitats, adult straying, and age variations in migration and reproduction. Fall Chinook salmon and winter steelhead have started to rebound in the Toutle River system, with increasing populations found in the Green and South Fork Toutle rivers. These and other fish populations have experienced substantial growth in localized stream reaches and lakes within the Toutle River basin; however, fish populations throughout the Toutle River have not returned to pre-eruption levels.

Although the Toutle River system provides an example of natural ecosystem resiliency, it is important to note that post-eruption recovery has not been free from human influence. Federal and state agency responses to the eruption have included construction of a large sediment retention structure, channel dredging, diking, and salvage logging. Ongoing land use practices such as forestry, agriculture, as well as fish management practices including, harvest and artificial production, continue to limit recovery of anadromous fish populations (LCFRB 2004).

1. Introduction

The 1980 eruption of Mount St. Helens triggered a massive debris avalanche and mudflows that dramatically altered the rivers in the immediate vicinity. Aquatic habitats, in particular those within the Toutle River subbasin, were decimated. It was estimated that over 125 miles of Toutle River fish habitat was inundated with debris, mud, ash, fragmented rock, and deposits of dead wood. High mortality of fish occurred in some stream reaches and tributaries, while other habitats offered refuge from the disturbance. Historically, the rivers that drained Mount St. Helens were among the most productive for fish in the State of Washington. The Toutle River in the aftermath of the eruption represents an example of a river system where segments of the anadromous fish[1] populations were decimated, yet within 5 to 10 years had experienced substantial recovery (Bisson et al. 2005). To date, little information exists on the recovery of fish populations following major natural disturbances (Bisson et al. 2005). However, a number of fish studies implemented in the Toutle River basin after the Mount St. Helens eruption provide a solid platform to evaluate the factors that have contributed to or limited the recovery of fish populations in the 30 plus years since the eruption.

The purposes of this document are to: 1) describe the aquatic habitat and fish population recovery in the Toutle River system, 2) identify factors influencing the recovery and 3) describe mechanisms that provide resiliency to aquatic systems subject to periodic environmental perturbation. To achieve these objectives, literature describing pre-eruption conditions in the Toutle River system, effects of the eruption on aquatic habitat and fish resources, the recovery of these resources in the aftermath of the eruption, and limitations on recovery was reviewed and is reported on herein. Owing to their cultural and ecological importance, the discussion focuses on salmonids. Case studies of Toutle River fall Chinook salmon and winter steelhead are provided to illustrate population trends and recovery.

2. Geographic Description

The Toutle River basin (approximately 513 square miles) is located on the western slope of the Cascade Range in southern Washington and has three principal tributaries: the North Fork Toutle River, the South Fork Toutle River, and the Green River (Figure 1; LCFRB 2004). The mainstem Toutle River extends from its mouth at the Cowlitz River (river mile [RM] 20; approximately five miles north of Castle Rock, Washington) to the North Fork and South Fork Toutle River split at RM 22 near Toutle, Washington (USACE 2007). The South Fork Toutle River is approximately 25 miles long with its headwaters on the west and northwest flanks of the volcano. The North Fork Toutle River headwaters are located north of the volcano and flows for approximately 30 miles before joining with the South Fork Toutle River. The Green River is a tributary to the North Fork Toutle River (RM 12.5) and has a length of approximately 37 miles. Its headwaters are located a few miles further north than the North Fork Toutle River headwaters. Forestry is the dominant land use in the Toutle River basin (USACE 2007). The Toutle River drains into the Cowlitz River, which is a major tributary to the Columbia River.

[1] Anadromous fish are fish species that are born in fresh water, spends most of its life in the sea and returns to fresh water to spawn.

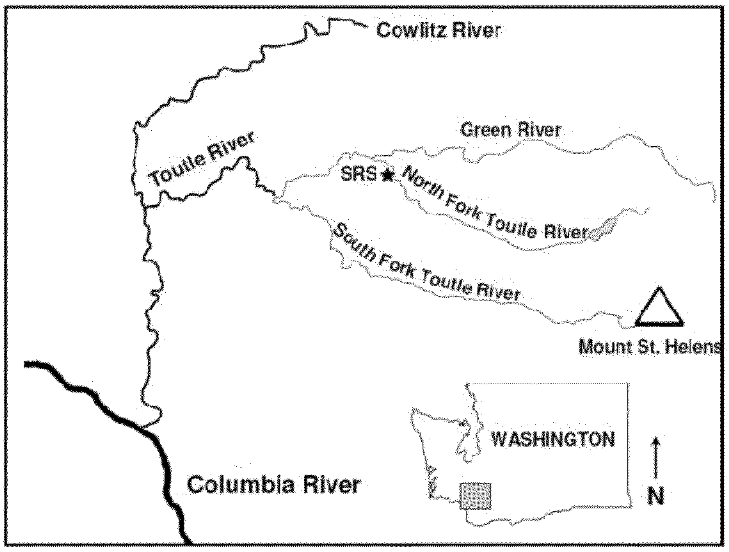

Figure 1 – Location of the Toutle River, its principal tributaries (the North Fork Toutle, South Fork Toutle, and Green rivers), Mount St. Helens, and the Sediment Retention Structure (SRS).
Source: AMEC, 2010.

Along with the Lewis, Kalama, and Cispus rivers, the Toutle River is one of four major river systems in the Mount St. Helens region (Swanson et al. 2005). Like the Toutle River, the Cispus River drains into in the Cowlitz River. The Lewis and Kalama rivers are major tributaries to the lower Columbia River.

3. Pre-eruption Conditions

The geological history of the Mount St. Helens region is characterized by volcanic activity and several periods of glaciation (Swanson et al. 2005). This activity dates back 23 to 28 million years and is generally characteristic of the Pacific "ring of fire", where volcanic activity is triggered by geological forces operating within the Earth's mantle and crustal plates. This geological setting has broadly shaped the region's physiography and the geophysical dynamics of chronic and catastrophic volcano growth and decay. Landforms in the vicinity of t he volcano are representative of extensive, older geological terrain with a long history of erosion that has resulted in steep and rugged topography, or of more gently sloping terrain, where more recent volcanic deposits have accumulated to form broad fans of deposition.

Within the Toutle River system, specific geophysi cal characteristics (e.g., landforms, channel morphology, and soil structure) can be varied and diverse. This is in part due the various combinations of a suite of primary and secondary volcanic processes that occur within an eruptive period (Swanson et al. 2005). For example, in the North Fork Toutle River headwaters, an accumulation of a broad fan, resulting from pyroclastic-flow deposits on the north flank of Mount St. Helens, intermittently dammed the headwaters and thus led to the formation of Spirit Lake. On the other hand, mudflow deposits dominated the river channel and valley downstream of the pyroclastic-flow deposits as a result of massive mudflows from periodic breaching of the dam. Furthermore, several of these mudflows blocked flow from Outlet Creek, a tributary to the mainstem Toutle River, and over time led to the formation of Silver Lake. In general, this suite of processes, deposits, and landforms created numerous and varied types of habitat within the Toutle River basin.

Aquatic habitats in the Toutle River system included mainstem rivers, tributary streams, and lakes. Streams contained a variety of habitat types such as small, steep, cascade-dominant channels as well as riffles, glides, pools, and headwater seeps and springs (Swanson et al. 2005). Lakes within the watershed were created from various geological processes, such as past volcanic eruptions, landslides, and glaciation, and varied considerably in area, depth, elevation, and exposure to sunlight (Dahm et al. 2005). Most lakes were oligotrophic and were characterized by low nutrient concentrations, low phytoplankton, high light transmission, and cool temperatures. Reports of late-summer hypolimnetic oxygen depletion were less common, yet this condition was documented in two lakes (i.e., Spirit and Fawn lakes) prior to the eruption (Bortelson et al. 1976 cited in Dahm et al. 2005). The largest lakes in the Toutle River basin were Spirit Lake, a cold, subalpine lake located north of Mount St. Helens in the North Fork Toutle River headwaters, and Silver Lake, a relatively warm, low-elevation lake located on Outlet Creek. Several other smaller lakes were located within the basin, particularly in the Green River subwatershed.

Riparian habitat in the Toutle River watershed was composed primarily of coniferous trees (Swanson et al. 2005). These trees provided large woody debris to stream channels and thus played an important role in channel stability, channel complexity, and the creation of suitable adult holding and juvenile rearing habitat (Beechie and Sibley 1997). However, riparian conditions were far from pristine. Forestry practices such as clear-cutting, monoculture planting, and logging road development occurred in the region in the decades leading up to the 1980 eruption (Swanson et al. 2005) and remains as the dominant land use in the basin. Commercial forestland makes up over 90% of the Toutle basin except for the subwatersheds on the flanks of Mount St. Helens (LCRFB 2004). Thus, riparian function was at least somewhat impaired prior to the eruption, but effects of forestry practices and associated road networks and stream crossings specific to the Toutle River's aquatic habitat and fish populations have not been well-documented.

Aquatic habitats throughout the Toutle River were accessible to migratory fishes (Swanson et al. 2005). It has been estimated that this river basin contained approximately 175 miles of streams used by salmon, steelhead, and coastal cutthroat trout (Bisson et al. 2005). While there were some natural barriers (e.g., cascades, waterfalls) to fish migration in the system's smaller tributaries and lakes, the majority of the tributary and lake habitats had open connections with the mainstem and free access to fish. The only notable migration barrier was the North Toutle Hatchery fish trap, which was constructed in the 1950s on the Green River at RM 0.5 (LCFRB 2004).

Historically, the aquatic habitats in the Mount St. Helens region supported more native fish species than any other region in Washington and were among the most productive aquatic habitats for anadromous fish in southern Washington (McPhail and Lindsey 1986 cited in Bisson et al. 2005). In combination with other rivers in the region, Toutle River origin fish contributed to large commercial and recreational fisheries occurring in the Pacific Ocean and lower Columbia River, as well as smaller in-basin sport fisheries (LCFRB 2004). Given the long history of geologic disturbances in the Mount St. Helens region, it is thought that most fish species have undergone local extirpation and recolonization over time (Wydoski and Whitney 2003). The Columbia River and its other tributaries likely served as refugia for anadromous fish species during periods of disturbance and thus provided source populations for recolonization following the disturbance (McPhail and Lindsey 1986 cited in Bisson et al. 2005).

The composition of fish species within the Toutle River system prior to the 1980 eruption was not well-documented; however, Bisson et al. (2005) provide a list of species historically found in the Mount St. Helens region. This species-rich fish assemblage included four species of anadromous salmon, six species of anadromous and/or freshwater trout, five non-salmonid anadromous species, and 14 other resident fish species (Table 1). Most of these fishes were native to the region, yet six of them, sockeye salmon (*Oncorhynchus nerka*), brook trout (*Salvelinus fontinalis*), brown trout (*Salmo trutta*), lake trout (*S. namaycush*), American shad (*Alosa sapidissima*), and westslope cutthroat trout (*O. clarkii lewisi*), were introduced.

Table 1 – Fish species in the Mount St. Helens region prior to the 1980 volcanic eruption.

Family	Common Name	Scientific Name	Origin
Anadromous Pacific salmon			
Salmonidae	Chinook salmon	*Oncorhynchus tshawytscha*	native
	chum salmon	*Oncorhynchus keta*	native
	coho salmon	*Oncorhynchus kisutch*	native
	sockeye salmon	*Oncorhynchus nerka*	introduced
Anadromous &/or freshwater trout			
Salmonidae	brook trout	*Salvelinus fontinalis*	introduced
	brown trout	*Salmo trutta*	introduced
	bull trout	*Salvelinus confluentus*	native
	cutthroat trout	*Oncorhynchus clarkii*	native/introduced [a]
	lake trout	*Salvelinus namaycush*	introduced
	rainbow trout	*Oncorhynchus mykiss*	native
Anadromous non-salmonids			
Acipenseridae	green sturgeon	*Acipenser medirostris*	native
	white sturgeon	*Acipenser transmontanus*	native
Clupeidae	American shad	*Alosa sapidissima*	introduced
Osmeridae	eulachon	*Thaleichthys pacificus*	native
Petromyzonitidae	Pacific lamprey	*Lampetra tridentata*	native
Other resident fishes			
Catostomidae	largescale sucker	*Catostomus macrocheilus*	native
Cottidae	coast sculpin	*Cottus aleuticus*	native
	riffle sculpin	*Cottus gulosus*	native
	shorthead sculpin	*Cottus confusus*	native
	torrent sculpin	*Cottus rhotheus*	native
Cyprinidae	longnose dace	*Rhinichthys cataractae*	native
	northern pikeminnow	*Ptychocheilus oregonensis*	native
	peamouth	*Mylocheilus caurinus*	native
	redside shiner	*Richardsonius balteatus*	native
	speckled dace	*Rhinichthys osculus*	native
Gasterosteidae	three-spine stickleback	*Gasterosteus aculeatus*	native
Percopsidae	sandroller	*Percopsis transmontana*	native
Petromyzonitidae	western brook lamprey	*Lampetra richardsoni*	native
Salmonidae	Mountain whitefish	*Prosopium williamsoni*	native

[a] The anadromous form (coastal cutthroat trout, *Oncorhynchus clarkii clarkii*) is native to the Mount St. Helens region, whereas the resident form (westslope cutthroat trout, *Oncorhynchus clarkii lewisi*) is introduced.

Source: Adapted from Bisson et al. 2005.

Documentation of anadromous fish populations in the Toutle River basin was better than that for resident fishes due to their cultural and ecological importance. Nine stocks of anadromous fish were present in the Toutle River basin prior to 1980 (LCFRB 2004, Stockley 1981 cited in Gustafson et al. 2010) including: spring and fall run Chinook salmon (*O. tshawytscha*), chum salmon (*O. keta*), coho salmon (*O. kisutch*), summer and winter steelhead (*O. mykiss*), coastal cutthroat trout (*O. clarkii clarkii*), eulachon (*Thaleichthys pacificus*), and Pacific lamprey (*Lampetra tridentata*). All of these fish stocks, with the exception of summer steelhead, are believed to have been native or naturally occurring in the Toutle River basin prior to the eruption (Gustafson et al. 2010, LCFRB 2004, USACE 2007). Spring and fall Chinook salmon, coho salmon, and winter steelhead were distributed widely throughout the basin, including the mainstem Toutle, North Fork Toutle, South Fork Toutle, and Green rivers, as well as smaller tributaries (LCFRB 2004, USACE 2007); Spirit Lake supported natural populations of coho salmon, winter steelhead, and coastal cutthroat trout (Lucas and Weinheimer 2003). The distribution of chum salmon, coastal cutthroat trout, eulachon, and Pacific lamprey within the basin was not well-known (Gustafson et al. 2010, LCFRB 2004, USACE 2007). Among the anadromous fishes, fall Chinook salmon, coho salmon, and winter steelhead were the most abundant with historic run sizes on the order of 7,000 to 60,000 fish (Bryant 1949, LCFRB 2004).

The abundance and distribution of Toutle River anadromous fish populations prior to 1980 were subject to both harvest and hatchery practices (LCFRB 2004). Unfortunately, the extent and relative contribution of these impacts on natural populations was not well documented. With the exception of chum salmon, anadromous salmonids in the Toutle River basin have been harvested in sport fisheries since at least the 1950s. Fall Chinook and coho salmon were targeted by large commercial and sport fisheries in the ocean and lower Columbia River. Most salmon and steelhead runs in the Toutle River had hatchery components (LCFRB 2004, USACE 2007). From the 1950s to the time of the eruption, the North Toutle Hatchery operated with production programs for Chinook and coho salmon with a goal of ensuring adequate escapement to support commercial and sport harvests. In addition, out-of-basin summer and winter steelhead stocks were released to provide recreational fishing opportunities since 1970 and 1953, respectively (LCFRB 2004). Additionally, numerous lakes in the basin have been stocked with trout species since at least the early 1900s including: brook trout, rainbow trout, westslope cutthroat trout, coastal cutthroat trout, and lake trout (Lucas and Weinheimer 2003).

4. Effects of the Eruption on Aquatic Habitat and Fish Populations

The most devastating eruption-related impacts to the Toutle River were due to a massive debris avalanche and mudflows (Figure 2). The debris avalanche, which is the largest landslide in recorded history, buried the upper 17 miles of the North Fork with approximately 3.8 billion cubic yards of silt, sand, gravels, and trees (Swanson and Major 2005). Several mudflows were generated from primary eruption impacts (e.g., the debris avalanche, directed blast, and hot pyroclastic flows; Janda et al. 1981, Scott 1988, Waitt 1989). The largest and most destructive mudflow on May 18, 1980 was a secondary impact resulting from the debris avalanche in the North Fork. It sent 183 million cubic yards of mudflow down the North Fork and then continued 75 miles to the Columbia River (Fairchild and Wigmosta 1983 cited in Swanson and Major 2005). Along its path, it destroyed the North Toutle Hatchery, inundated floodplains, and entrained riparian vegetation and log piles from timber harvest camps. Sediment volumes and transport quickly became a major concern in the North Fork Toutle River subbasin (AMEC 2010, USACE 2007). The South Fork Toutle River was also heavily impacted by large and rapidly moving mudflows that were triggered by the blast and pyroclastic flows (Swanson and

Major 2005). The South Fork mudflow peaked within minutes after the eruption and left sediment deposits that ranged in depth from 3 feet in the middle stream reaches to 7-13 feet in the alluvial fan at the mouth of the stream (Janda et al. 1981). Several other mudflows have also occurred in the North and South Fork of the Toutle River since the time of the eruption leading to major changes in channel morphology and hydrology (Swanson and Major 2005).

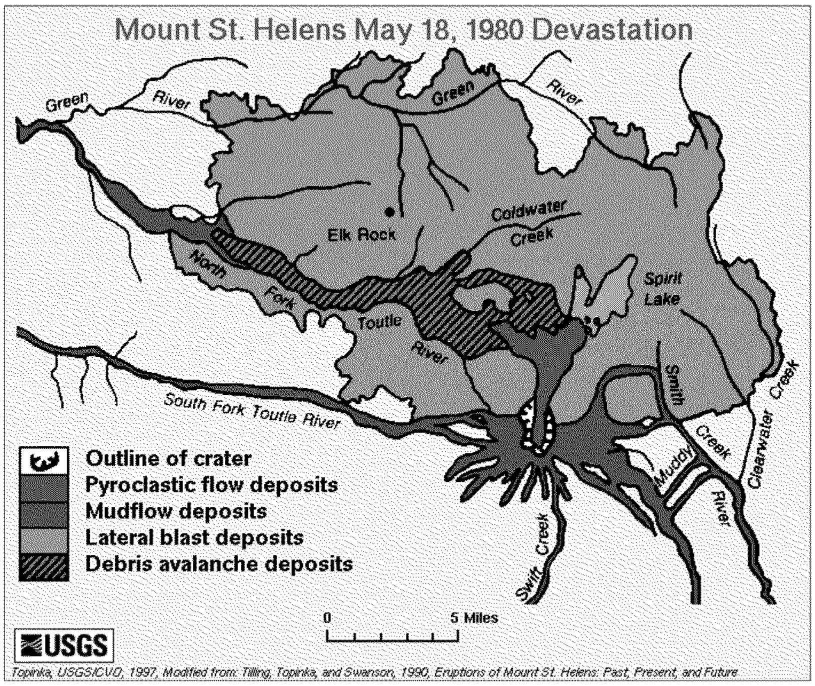

Figure 2 – Eruption deposits resulting from the May 1980 eruption of Mount St. Helens.

Source: U.S. Geological Survey, Cascades Volcano Observatory, 1997. (http://vulcan.wr.usgs.gov/Volcano es/MSH/Maps/may18_devastmap.htm

The combined effects of the debris avalanche and mudflows in the North Fork Toutle River resulted in the most devastating impacts in the basin (Figure 2). The South Fork was considered the second most impacted stream reach within the basin owing to extensive mudflows. Direct effects of the eruption on the Green River were comparatively much less than the forks and were limited primarily to ash and rock fragment deposits and riparian habitat loss as a result of a powerful lateral blast. The lateral blast leveled forests, and those areas left standing were scorched by massive heat from the blast cloud. The area of lateral blast also included the upper North Fork Toutle and South Fork Toutle subwatersheds. Although the mainstem Toutle River was not within the zone of direct impact, it has been dramatically affected by eruption impacts in its principal tributaries, and its floodplain was inundated with mudflows and fine sediments.

Both the immediate and secondary impacts from the May 18, 1980 eruption of Mount St. Helens were catastrophic to stream-dwelling fish populations inhabiting the Toutle River basin. Direct fish mortality resulted from high water temperature, abrasion, and suspended-sediment (Bisson et al. 2005). The level of fish mortality could not be documented; however, descriptions of stream habitat loss and degradation are useful for understanding the magnitude of impacts on fish populations. Of the 175 miles of accessible anadromous fish habitat in the Toutle River system, it has been estimated that 102 miles (58%), including the entire mainstem Toutle River, were inundated by the debris avalanche and mudflows and that an additional 33 miles (19%) of this habitat was impacted by ash, fragmented rock, and wood debris deposits (Martin et al. 1984). Entire tributary habitats were cutoff due to blockages created by mudflows. In addition, suspended sediment concentrations in the mainstem remained at levels (i.e., 300-1,000 mg/l) lethal to fish for six months (Stober et al. 1981).

Immediate effects on lake-dwelling fish populations varied with distance from and directional orientation to the volcano (Dahm et al. 20005) and with the type of eruption impacts affecting each lake, as well as lake habitat conditions at the time of the eruption (Bisson et al. 2005). The most dramatic alteration of lake habitat occurred in Spirit Lake, located five miles from the volcano in the North Fork Toutle River headwaters. The debris avalanche deposited materials in the lake raising the water level 197 feet, increasing its surface area by 80%, greatly reducing lake depth, and creating large shoal areas (Bisson et al. 2005, Dahm et al. 2005). The lake was subject to ash deposition and to hot flows of fragmented rock and gases and was within the extensive blow-down zone. It was reported as highly improbable that fish would have survived in Spirit Lake (Lucas and Weinheimer 2003). Prior to the eruption, Spirit Lake was connected directly to the mainstem North Fork Toutle River and supported coho salmon, winter steelhead, and coastal cutthroat trout. After the eruption, the lake outlet elevation was raised and remained unstable until 1985, when a tunnel was constructed to transfer water from the lake to South Coldwater Creek (Glicken et al. 1989 cited in Swanson and Major 2005). In addition to physical changes, Spirit Lake underwent dramatic chemical and biological changes as well. Water quality declined immediately, and aquatic biota perished (Dahm et al. 2005).

Similar to Spirit Lake, lakes within the blow-down zone that lacked ice cover at the time of the eruption, had insufficient depth, and/or were subject to high suspended sediment loads from tributary streams experienced high or complete fish mortality (Bisson et al. 2005). Other lakes within the blow-down zone had ice and snow cover at the time of the eruption and subsequently experienced diminished impacts. Acute impacts to fish were reduced in lakes with ice cover and depth as these elements offered protection and/or refugia (Bisson et al. 2005). After the blast when surface ice melted, the blast material, ash fall, and organic constituents from the leveled and scorched forests reached lake waters and resulted in reduced water clarity (Wissmar et al. 1982). Suspended materials eventually settled to lake bottoms, and water quality conditions improved by late summer 1980 (Crawford 1986). Lakes that were impacted only by rock fragment and ash fall deposition were relatively unaffected by the eruption (Wissmar et al. 1982). In these lesser-impacted lakes, effects on water quality, invertebrate abundance, and trout spawning habitat were minimal and/or transient (Bisson et al. 2005). Fish populations in these lakes survived the primary and secondary eruption impacts and continued to have self-sustaining populations of trout.

Localized stream reaches also were subject to a variety of eruption-related impacts (Bisson et al. 2005). Streams within the blow-down zone, such as those in the upper North Fork Toutle and Green rivers, were highly exposed and subject to warming by direct solar radiation. These streams also experienced high sediment influxes from hill slope erosion and landslides, and some streams were subject to debris flows containing large wood. Log jams formed in small headwater streams and may have blocked salmon and trout access. Mudflows in the North Fork Toutle River and South Fork Toutle River subbasins resulted in elevated sediment terraces along the lesser-confined channel margins and in some cases cutoff access to tributaries. New channels were formed as tributary flows cut across mudflow terraces and entered mainstem channels. These new channels lacked riparian vegetation and other structural elements.

Dramatic channel modifications resulted from the voluminous debris deposits and mudflows. For streams that only received sediments from the blast and airfall deposits, recovery to background levels was relatively rapid occurring within five years (Meyer and Martinson 1989). However, channels receiving extensive deposition from the lahars and debris avalanches, specifically the North Fork Toutle River, experienced large-scale adjustments for more than fifteen years (Meyer and Martinson 1989). For example, mudflows initiated channel formation in the lower half of the avalanche deposit in the North Fork Toutle River (Swanson and Major 2005, Meyer and Martinson 1989). In addition, the pumping and seasonal runoff from Spirit Lake led to approximately 35% of the avalanche deposit surface being reworked and replaced by braided channels and terraces within a ten-year period. Channels across the debris deposit were widened by hundreds of yards, incised by tens of yards, and were aggraded locally by several yards (Major et al. 2000). In addition, two new lakes (i.e., Coldwater and Castle lakes) were formed on the surface of the avalanche deposit during the first three years after the eruption (Bisson et al. 2005, Swanson and Major 2005). These changes in channel morphology greatly influenced the hydrology of the Toutle River basin and subsequently, the recovery of aquatic and riparian habitats.

The effects of sediment yields were extensive in both space and time (AMEC 2010, USACE 2007). More than 45 million cubic yards of sediment were deposited in the Columbia River, and the carrying capacity of the lower Cowlitz River was reduced by 85% (AMEC 2010). Flooding and river navigation concerns below the Toutle River required levees to be raised near the Columbia River, and over 100 million cubic yards of sediment was dredged, primarily from the Columbia and Cowlitz rivers (AMEC 2010, USACE 2007). Within the Toutle River system, temporary flood control measures were installed on the North Fork Toutle and South Fork Toutle rivers. The flood control structure on the North Fork Toutle River was breached several times, causing downstream floods, and became totally ineffective by 1983.

Sediment yields in the Toutle and North Fork Toutle rivers remained above estimated background levels (Swanson and Major 2005) which prompted the United States Army Corps of Engineers (USACE) to construct a large sediment retention structure (SRS) on the North Fork Toutle River at RM 13.2 (USACE 2007). The SRS was built to minimize downstream sediment transport to prevent the disruption of navigable waterways in the Toutle, Cowlitz, and Columbia rivers. The SRS, completed in 1989, is an earthen dam that is 125 feet above the original streambed, 1,800 feet long, and 184 feet high; it included a series of concrete outlet structures to accommodate downstream fish passage. However, in the 25 years since the construction of the SRS, sediment loading upstream and sediment transport over the SRS have resulted in aquatic habitat degradation and both upstream and downstream fish passage concerns (AMEC 2010, Bisson et al. 2005, USACE 2007, USACE 2012). (See Section 6 for further detail.)

Figure 3 – U.S. Army Corps of Engineers sediment retention structure, North Fork Toutle River, Washington, 1990.

Source: U.S. Army Corps of Engineers Digital Visual Library

5. Recovery of Aquatic Habitat and Fish Populations

Although the eruption had immediate catastrophic effects on stream habitat and likely resulted in high fish mortality throughout the Toutle River basin, some fish survived the initial effects of the eruption (Martin et al. 1981, Martin et al. 1984). In the spring of 1981, outmigrant trapping in Deer Creek, a mudflow-impacted tributary to the North Fork Toutle River, revealed that juvenile coho salmon, steelhead, and cutthroat trout had survived and were migrating out of the system (Martin et al. 1981). Juvenile steelhead and cutthroat trout were observed in other mudflow-impacted tributaries in the North Fork and South Fork Toutle River subbasins (e.g., Wyant, Johnson, and Herrington creeks; Martin et al. 1984). In the Green River subbasin, salmonid survivors were observed in Elk Creek, which was impacted only by ash and fragmented rock deposits. Survival in stream reaches affected by the massive debris avalanche was less likely, yet two juvenile cutthroat trout were found in an upper reach of Bear Creek, a tributary to the North Fork Toutle River.

These instances of fish survival have been attributed to varying degrees of impact and the presence of refugia within localized stream reaches (e.g., Crisafulli and Hawkins 1998, Hawkins and Sedell 1990, Martin et al. 1984). In the case of Bear Creek, Martin et al. (1984) suggested that a steep valley wall shielded the upper stream reach from the powerful eruption blast and avalanche debris. Similarly, the upper reaches of the mudflow-affected tributaries in the North Fork and South Fork Toutle River subbasins likely provided refugia from the more heavily impacted mainstem habitats and lower tributary reaches, even though habitat conditions in some of these streams were less than optimal for juvenile salmonid survival (Martin et al. 1982 cited in Bisson et al. 2005, Martin et al. 1986). Refugia were also likely present at finer spatial scales. For example, in the nearby Lewis River watershed, resident cutthroat trout and sculpin survived in the upper stream reaches of Clearwater Creek. It was hypothesized that springs, stable large wood structures, and local un-impacted patches of habitat served as refugia in this tributary (Hawkins and Sedell 1990). Hawkins and Sedell (1990) noted that the recovery of fish populations in Clearwater Creek following the eruption was dependent on the existence of freshwater refugia and that fish seeking refuge in even marginal habitats were important sources for recolonization once aquatic habitat conditions improved.

The life history diversity exhibited by anadromous salmonids offers additional mechanisms for coping with environmental disturbance. Several attributes of anadromous salmon life history strategies enable them to find temporal and/or spatial refuge from highly disturbed environments and then return to natal habitats when conditions improve (Quinn 2005, Swanson et al. 2005). These attributes include the high mobility of juvenile and adults across habitats, adult straying, and age variations in outmigration and spawning returns (Quinn 2005). Juvenile salmonids have the ability to move both upstream and downstream within their freshwater rearing habitats. Prior to outmigrating as smolts, they may travel 18 miles or greater from their rearing site, depending on the species and stream habitat characteristics such as stream flow and gradient (Quinn 2005). In the Toutle River system, adult salmon migrate nearly 93 miles just along the course of the Columbia and Cowlitz rivers. Moreover, although most adult salmon return to their natal streams to spawn, some adults from each population stray to other rivers or streams for spawning. This exploratory behavior exposes fish to potential new habitats and is particularly important when successful reproduction in the natal stream is unlikely due to severe disturbance. Finally, all anadromous salmon species exhibit life histories where one or more age classes leave their natal stream and rear at sea for several years. Subsequently, adults from the same brood year return to natal streams to spawn over a period of several years. This variation in age at migration spreads out the risk to any one brood year over as many as eight years, depending on the species (Groot and Margolis 1998). For example, Chinook salmon from a given brood year may outmigrate as age 0, 1 or 2+ juveniles and may spend two to six years in marine and estuarine habitats before returning to spawn. Thus, fish from this brood year are expected to be present in the adult spawning runs for the next two to eight years. In addition, the spawning runs in any one year include adults from multiple brood years, such that each spawning run is composed of several age classes of fish. These life history traits enable anadromous salmon to use both marine and freshwater habitats as refugia to escape local environmental disturbance and allow for recolonization of natal habitats within a several year window after acute environmental disturbances.

Even with the ocean as a refuge from direct impacts, adult salmon and steelhead returns to the Toutle River were scarce in the first three years after the eruption (Leider 1989, Martin et al. 1984). Coded-wire tag recovery data for fall Chinook and coho salmon released as smolts in the Toutle River basin prior to the eruption indicated that the majority of returning adults in 1980 and 1981 strayed to other lower Columbia River and Cowlitz River tributaries (Martin et al. 1984). In the six years prior to the eruption, few adults strayed into other systems. Similarly, estimates of adult steelhead strays in relatively unaffected tributaries to the Columbia River increased from 16% under pre-eruption conditions to 45% post-eruption, and it was presumed that several of these strays originated from the Toutle River (Leider 1989). These increases in straying have been attributed to behavioral responses of adult fish to harsh water quality conditions (e.g., high water temperatures, suspended sediments, and ash content) that were present in the Lower Cowlitz and Toutle rivers (Leider 1989, Martin et al. 1984, Whitman et al. 1982).

Although straying into lower Columbia River tributaries appeared to increase, some adult spring and fall Chinook salmon, coho salmon, and steelhead did return to accessible habitats within the Toutle River system in 1981 (Martin et al. 1981, Martin et al. 1984). Returning adults and/or redds were observed in tributaries to the North Fork Toutle (i.e., Alder, Deer, and Wyant creeks), South Fork Toutle (i.e., Herrington, Studebaker, and Johnson creeks), and Green rivers (i.e., Devils and Elk creeks; Martin et al. 1984). In the case of Deer Creek, where numerous adult spring Chinook salmon were sighted in June 1981, Martin et al. (1981) hypothesized that these fish were avoiding the mainstem North Fork Toutle River, which had relatively higher water temperatures and suspended sediment concentrations than Deer Creek.

Spawning locations of these returning adults appeared to be independent of eruption impacts (Martin et al. 1984). In Wyant Creek, 39 steelhead redds were observed in the lower 875 yards of the stream that had been affected by mudflows, whereas only two redds were observed in the 519 yards immediately upstream of the mudflow-affected area. Coho salmon and steelhead redds in lower Wyant Creek, as well as Studebaker and Cline creeks, were constructed on mudflow substrates containing high levels of fine sediments and sand. Abundant fry were observed in these spawning reaches in the spring of 1982 indicating that spawning was successful despite high percentages of fine substrates. Similar evidence of natural spawning success for Chinook salmon, coho salmon, and steelhead was found in other affected tributaries within the Toutle River system (Martin et al. 1984). Martin et al. (1984) attributed this spawning success to the high water content of mudflow deposits, the hardening of the streambed surfaces, and the subsequent formation of groundwater upwelling areas that provide sufficient levels of dissolved oxygen for embryonic survival and development.

The recovery of aquatic habitats is also of critical importance for the long-term re-establishment of self-sustaining fish populations (Bisson et al. 2005). Aquatic habitat recovery, in turn, is dependent on a diverse suite of biological, ecological, and geophysical processes and interactions, such as riparian habitat development, thermal regulation of water temperatures, erosion, sediment transport and deposition, aquatic primary productivity, prey availability, and predator/competitor interactions (Swanson and Major 2005). Initial stream habitat devastation, which was characterized by high sediment levels, high and variable water temperatures, and the destruction of food resources, was followed by increases in primary productivity and the abundance of aquatic and terrestrial invertebrates (Bisson et al. 2005). In 1981 and 1982, Martin et al. (1986) found that stocked juvenile coho salmon survived poorly in volcanically disturbed streams in the Toutle River basin. According to Martin et al. (1986), mortality during summer months was likely due to lethal and highly variable water temperatures, whereas mortality during winter months was attributed to a lack of instream cover and habitat complexity. However, Bisson et al. (1988) found that from 1983 to 1986 juvenile coho salmon production in Hoffstadt, Herrington, and Schultz creeks had increased dramatically, and by 1986, it was nearly twice that of nearby streams with old-growth riparian habitat (Bilby and Bisson 1987). Relatively warm summer water temperatures (e.g., as great as 85 degrees Fahrenheit) coincided with periods of high coho salmon productivity (Bisson et al. 1988). This relatively high fish productivity has been attributed to an increase in primary productivity, an abundance of aquatic and terrestrial food sources, and the relative absence of predators and competitors.

Bisson et al. (2005) continued to monitor Hoffstadt, Herrington, and Schultz creeks until 2002. Despite potentially lethal temperatures, these streams continued to support salmon and trout. Hoffstadt Creek was severely disturbed by primary and secondary eruption impacts, such as blow-down and post-eruption debris flows that scoured the channel to nearly bedrock. Juvenile steelhead and coho salmon were stocked in Hoffstadt Creek in the 1980s. Bisson et al. (2005) found that these fish survived and grew at rates greater than or equal to those in relatively undisturbed streams. Progeny of stocked adult steelhead also survived well, and cutthroat trout persisted in the upper stream reaches where competing steelhead were absent. Survival mechanisms are unknown, although fish may have sought refuge in cool groundwater seeps or other thermal refugia (Hawkins and Sedell 1990). Episodes of potentially lethal water temperatures in Hoffstadt, Herrington, and Schultz creeks declined throughout the 1990s, largely due to the re-establishment of riparian vegetation which provided shade for the stream channels (Bisson et al. 2005). As temperatur es decreased, primary productivity and stream-dwelling fish abundances gradually returned to levels that were more typical of other streams in the western Cascade Mountains.

Rates of spawning habitat recovery were dependent on the type of eruption impact, as well as the location of the spawning habitat within the watershed (Martin et al. 1984). Spawning gravels from streams in the Green River watershed, which was affected only by ash, fragmented rock, and large wood deposits, had lower fine sediment concentrations than those from streams in the North Fork Toutle River and South Fork Toutle River subwatersheds. Within the North Fork Toutle River subbasin, streams traversing the debris avalanche deposit had greater fine sediment concentrations than those traversing mudflow deposits. Between 1981 and 1982, decreases in fine sediment concentrations were observed in some stream reaches. Sediment flushing was related to stream reaches with high winter flows and high localized gradients. In many portions of the South Fork Toutle River and Green River subwatershed, the original gravel-cobble streambeds had recovered within one to three years (Bisson et al. 2005); however, spawning habitat quality elsewhere has not yet recovered (LCFRB 2004).

Lake-dwelling salmonids, such as rainbow, cutthroat, and brook trout, survived initial eruptions impacts in several lakes in the upper Green River and North Fork Toutle River watersheds (Lucas and Weinheimer 2003). This survival was largely dependent on lake depth and the presence of ice cover at the time of the eruption (Bisson et al. 2005). However, longer-term fish population responses to the eruption appeared to be dependent on habitat conditions such as light transmission, primary productivity, nutrient levels, prey availability, predator/competitor absence, and spawning substrates (Bisson et al. 2005, Crawford 1986). Light transmission was initially reduced in lakes as a result of material deposition, and this may have had a short-term effect on the aquatic food web (Crawford 1986). Lakes in the blow-down zone were enriched with nutrients from the leveled and scorched forests (Bisson et al. 2005). As water clarity improved and light transmission increased, primary productivity also increased, and zooplankton communities rebounded (Crawford 1986). Benthic invertebrate populations may have been negatively affected by deposition on lake bottoms, yet a diversity of benthic invertebrates was found in fish stomach samples collected in from 1980 through 1983 (Crawford 1986).

Bisson et al. (2005) conducted an assessment of fish population responses in 19 lakes that were likely to have supported fish prior to the eruption. All of these lakes were located in the blow-down zone, and most were within the North Fork Toutle River and Green River subbasins. Fish populations in 13 of these lakes initially survived the eruption impacts. Over the next 20 years, breeding populations were observed in each of these 13 lakes. There was only one documented extirpation during this time period; introduced westslope cutthroat trout were lost from one of the lakes. Between 1993 and 2001, recolonization of brook trout occurred in two of the six lakes that experienced complete fish mortality; however, the colonists were likely transplanted by anglers (Lucas and Weinheimer 2003). No other fish population recovery was documented in lakes that initially experienced complete mortality as a result of the eruption. Since 1980, the Washington Department of Fish and Wildlife (WDFW) has stocked fish, primarily cutthroat trout and to a lesser extent rainbow trout, in some of the lakes within the blow-down zone (Lucas and Weinheimer 2003). The success of cutthroat trout stocking has been dependent on the presence of brook trout populations, as brook trout often out-compete cutthroat trout. In the one lake where rainbow trout have been stocked, spawning success has been limited (Lucas and Weinheimer 2003).

Limnological and fish surveys conducted in Spirit Lake throughout the 1980s were unable to document fish survival or presence (Crawford 1986). However, from 1993 to 1997, directed sampling efforts resulted in a single rainbow trout captured each year (Lucas and Weinheimer 2003). Sampling efforts were increased from 2000 through 2002 during which time, 151 rainbow trout, representing multiple age classes, were captured. The age class structure indicated that successful spawning had occurred; however, efforts to identify spawning areas were unsuccessful. Lucas and Weinheimer (2003) speculated that spawning had occurred in the lake tributaries or in upwelling areas along the lake shore. As no source of colonists could be identified, it was suspected that the recolonizing trout were illegally stocked in Spirit Lake.

Despite the fish origin, the recolonization of Spirit Lake demonstrated the aquatic habitat's resilience to disturbance. Highly degraded conditions, such as elevated water temperatures, anoxic waters, reduced metals, low light transmission, turbidity, and loss of flora and fauna, persisted in Spirit Lake for at least the first two years after the eruption (Dahm et al. 2005). However, even during this time changes were occurring. A prolific heterotrophic microbial community developed. Large woody debris and other forest debris formed a large log mat that covered approximately 40% of the lake's surface and provided the lake with an enriched nutrient source. Fine organics were decomposed by heterotrophic bacteria. Precipitation and stream flows diluted metal and nutrient concentrations. As early as 1982, water quality was beginning to improve dramatically, and phytoplankton, zooplankton, and aquatic invertebrate communities were beginning to develop. By the early 1990s, when rainbow trout were observed in the Spirit Lake, water quality conditions had improved substantially, and a prey base that could support a fish population had been established (Bisson et al. 2005).

In the two new lakes that were formed in the first three years after the eruption, self-sustaining trout populations were established by the mid-1990s (Bisson et al. 2005, Lucas and Weinheimer 2003). In Coldwater Lake, 30,000 subyearling rainbow trout fry were stocked in 1989. By 1997, age-class analyses indicated that a healthy and vigorous population of rainbow trout had been established (Lucas and Weinheimer 2003). In 2001, westslope and resident coastal cutthroat trout were also found in the lake. Lucas and Weinheimer (2003) suspect that westslope cutthroat trout were inadvertently stocked along with rainbow trout in 1989 and that coastal cutthroat trout colonized Coldwater Lake from other tributary streams where survival from the initial eruption impacts had occurred. In Castle Lake, the first observations of fish occurred in 1991, when age 2+ hatchery rainbow trout were during angling and gill net surveys (Lucas and Weinheimer 2003). These colonists appeared to be emigrants from Coldwater Lake, although Lucas and Weinheimer also acknowledge the possibility that some fish residing in Castle Creek survived the eruption.

During the formation of Castle and Coldwater lakes, habitat conditions were not suitable for supporting trout, yet by the late 1980s conditions had greatly improved (Dahm et al. 2005). During the early 1980s, lake water quality conditions were generally similar to those in Spirit Lake. Water quality was characterized by low light transmission, anoxic waters, high ion and nutrient concentrations, high dissolved organic carbon, and high microbial activity. By 1989, water quality had greatly improved due to reduced dissolved organic carbon concentrations, dilution, and the development of phytoplankton, zooplankton, and aquatic insect communities. Dissolved oxygen concentrations in the epilimnion had increased to levels capable of supporting fish (Dahm et al. 2005).

Despite the devastating impacts of the eruption on aquatic habitat and immediate fish mortality, many fish populations recovered in the Toutle River system more quickly than managers and biologists thought possible (Bisson et al. 2005). The post-eruption rebound of both stream-dwelling and lake-dwelling fish populations appears to have been driven by complex biological and ecological processes: involving life history variations; habitat refugia; aquatic habitat connectivity; increased primary productivity; survivors and colonists; prey abundance; and competitor and predator absence.

In addition to natural processes, there have been some fisheries management actions that likely fostered population recovery. These include a sport fishery harvest moratorium and fish stocking. Recreational fisheries for salmon and steelhead in the Toutle River basin were closed immediately after the eruption and remained closed until 1987 (Lucas and Pointer 1987 cited in Bisson et al. 2005). These closures coincided with increases in the abundance of returning adults and juveniles rearing in streams, particularly for winter steelhead. Aggressive stocking of both anadromous and freshwater salmonids was used to re-establish populations and bolster recovery (Bisson et al. 2005). It is believed that this stocking contributed to the post-eruption rebounds observed throughout the 1980s.

6. Limitations on Recovery

The human response to the Mount St. Helens eruption has unarguably played a major role in ecosystem recovery. The condition of habitat features of particular significance to salmonid species including watershed hydrology, passage obstructions, water quality, key habitat availability, substrate and sediment, woody debris, channel stability, riparian function, and floodplain function are influenced by both natural (i.e., post-eruption sedimentation) and human induced (i.e., land use and fish management practices) components. Federal and state agency responses to the eruption have included the construction of a sediment retention structure (SRS), channel dredging, diking, and salvage logging. Ongoing management actions such as forestry, agriculture, fish harvest, and hatchery practices continue to affect natural recovery. The extent to which these activities contribute to, or hamper, ecosystem recovery is difficult to partition out from that which is attributable to natural recovery.

Although hatchery production and outplanting was instrumental to initiate recovery after the eruption, the role that hatchery management practices have had on the long-term recovery of salmonid populations is less clear, particularly due to the effects of hatchery fish on natural populations (LCFRB 2004). Adverse effects from interactions between artificially produced fish and those that spawn naturally are well documented in the literature. Nevertheless, hatchery programs that existed prior to the eruption were re-established for summer steelhead in 1981 and for fall Chinook and coho salmon in 1990, when the North Toutle Hatchery was rebuilt. Summer steelhead hatchery programs currently operate in the South Fork Toutle and Green River and are limited to the acclimation and release of Skamania stock. The winter steelhead hatchery program was discontinued.

A limiting factors analysis conducted for the Lower Columbia Subbasin Plan (LCRFB 2004) determined that for most species (i.e., spring Chinook salmon, chum salmon, coho salmon, and winter steelhead) within-basin stream habitat conditions have the greatest impact on population health and viability, relative to the other factors addressed (i.e., hydropower operations, harvest, hatcheries, estuary habitat, and ecological interactions).

The Lower Columbia Subbasin Plan (LCRFB 2004) included an analysis to identify the limiting habitat factors and threats to habitat and fish recovery within the mainstem and tributary reaches. The results of this analysis, as summarized below, are useful for understanding differences among reaches with respect to their current and potential production for Toutle River salmon and steelhead.

- The Green River and its tributaries, which were spared from the most devastating eruption impacts, support important current and potential production for fall Chinook salmon, coho salmon, and winter steelhead. However, blow-down effects and forestry management practices, such as timber salvaging and associated road construction, have contributed to altered stream flows, reduced bank and soil stability, altered habitat unit composition, erosion and sedimentation, and reduced large wood recruitment.

- The South Fork Toutle River provides important habitat for fall Chinook salmon, coho salmon, and winter steelhead. The upper reaches are valuable for winter steelhead and fall Chinook salmon, whereas the lower reaches have good current and potential habitat for fall Chinook and coho salmon. Aquatic habitats in the South Fork Toutle River have experienced significant recovery since the early 1980s. However, they are still subject to threats and impacts associated with forest harvest practices, as described above for the Green River.

- Potentially productive reaches were identified in the mainstem Toutle and North Fork Toutle rivers. The lower mainstem Toutle River has potentially productive habitat for fall Chinook, chum, and coho salmon. In the North Fork Toutle River, the two areas with the most production potential are located just downstream of the Green River confluence and between Hoffstadt and Castle creeks. In addition to the forest management threats described above, the recovery of the Toutle and North Fork Toutle rivers is also compromised by continued erosion of the massive avalanche deposit and by sediment control measures that have been employed since the early 1980s (LCFRB 2004, USACE 2007). Thus, recovery to pre-eruption conditions has not yet occurred in these streams. The LCFRB (2004) found that effective recovery measures for the Toutle and North Fork Toutle rivers will need to entail reducing channel confinement, restoring riparian areas, and addressing the continued supply of sediment from the SRS.

Long-term effects associated with the avalanche deposit occur both upstream and downstream of the SRS. By 1998, approximately 105 million cubic yards of sediment had settled out in the four-mile reach upstream of the SRS, and the outlet structures through which water and fish passed became blocked off due to sediment infill upstream of the SRS (USACE 2007). Since this time, the North Fork Toutle River flows over the spillway of the SRS. The sediment trapping efficiency of the SRS has decreased from 92% in 1989 to 31% in recent years and continues to decline (USACE 2012). The current average annual total sediment load passing over the SRS is estimated to be over 4 million cubic yards (USACE 2010). Recent and past sediment loads have led to the degradation of aquatic and floodplain habitats in the Toutle River mainstem (Major et al. 2000), and channel dredging and floodplain spoils placement have further contributed to the habitat degradation (LCFRB 2004). Upstream of the SRS, the sediment plain consists of a highly braided and mobile stream network with shallow flow and sparse vegetation (USACE 2012). Formation of a typical cascade stream is impeded by the wide channel valley and moderate slope. The SRS has also caused sediment buildup in the lower reaches of Hoffstadt and Alder creeks and thus, has contributed to the degradation of some of the highest quality coho salmon and steelhead spawning areas that existed prior to the eruption (Bisson et al. 2005).

The SRS also presents upstream and downstream fish passage concerns (AMEC 2010, USACE 2007). Initially, it completely prevented volitional upstream passage, blocking access to more than 50 miles of upstream anadromous fish habitat (USACE 2007). To mitigate for losses in accessible habitat, the USACE constructed a trap-and-haul fish collection facility in 1989. The facility is located on the North Fork Toutle River at RM 11.9, 1.3 miles downstream of the SRS. Adult coho salmon and steelhead are trapped at this facility, trucked upstream, and released into Hoffstadt and Alder creeks, as well as Bear Creek in recent years (AMEC 2010). Downstream passage was initially possible via the SRS outlet structures, but in 1989 when the pipes were buried in sediment, downstream passage occurred over the SRS spillway.

However, there have been ongoing fish passage and trapping concerns. Currently, adult coho salmon and most adult steelhead are unable to volitionally pass the SRS and thus are dependent on trap-and-haul operations to reach upstream spawning grounds (AMEC 2010). Since the time of its construction, the fish collection facility has suffered from operational problems associated with high flows and sediment loads (USACE 2007). Currently, it is in severe disrepair, has a low trapping efficiency rate, and is expected to become entirely dysfunctional by 2015 (AMEC 2010). SRS spillway modifications have been made to increase downstream passage survival, although with limited success. For example, Olds (2002) estimated that 22% of coho salmon smolts passing over the spillway of the SRS received external injuries (cited in USACE 2007). The USACE, WDFW, and regional salmon recovery technical groups are still addressing fish passage concerns as of 2012 (AMEC 2010, LCFRB 2004, USACE 2007, USACE 2012). To recover fish populations in the upper North Fork Toutle River potential long-term solutions for managing sediment impacts upstream and downstream of the SRS must be coordinated with fisheries conservation efforts (AMEC 2010, USACE 2007).

7. Toutle River Fish Population Recovery Case Studies

Fall Chinook salmon and winter steelhead are both listed as threatened under the Endangered Species Act (ESA), yet these populations have demonstrated remarkable resiliency in the 30 years since the eruption. In this section, the recovery of these two species is explored in further detail. Specifically, these accounts describe: historic and current distribution and abundance, population responses to the eruption, the role of hatchery programs operating in the Toutle River basin, and factors that are currently limiting to the re-establishment of healthy and viable populations.

7.1 Toutle River Fall Chinook Salmon

Historically, the distribution of fall Chinook salmon in the Toutle River basin included the mainstem Toutle, North Fork Toutle, South Fork Toutle, and Green rivers. Historic abundance estimates in the basin ranged from 15,000 to 20,000 adults (LCFRB 2004, USACE 2007). WDFW also estimated a historic abundance of 25,392 spawners using the ecosystem and diagnosis treatment (EDT) model (Busack and Rawding 2003); historic habitat conditions utilized in the model were presumably reflective of pre-eruption conditions. In the early 1950s, annual escapement for the Toutle River system was estimated to be 6,500 adults (WDW 1990) with an estimated 80% of spawning occurring in the lower five miles of the mainstem Toutle River (WDF 1951 cited in USACE 2007). Hatchery production was a component of fall Chinook salmon production in the Toutle River system since at least 1951 through 1979, until the North Toutle Hatchery was destroyed in the 1980 eruption. From 1964 to 1979, total returns to the Toutle River averaged 10,756 adults; of these fish, spawners of both hatchery and natural origin averaged 6,573 fish (Kreitman 1981 cited in WDW 1990). During this same period, the distribution of spawners was 49.4% in the North Fork Toutle River, 42% in the Green River, 4.8% in the mainstem Toutle River, and 3.8% in the South Fork Toutle River. Spawning was reported to occur as far upstream as Coldwater Creek on the North Fork Toutle River and up to Spirit Lake (USACE 2007; WDF 1973 cited in Dammers et al. 2002). In addition, it was estimated that there were approximately 20 miles of fall Chinook salmon spawning and rearing habitat available in the mainstem Green River upstream of the North Toutle Hatchery (WDF 1973 cited in Dammers et al. 2002).

Adult fall Chinook salmon return to the Toutle River system to spawn in mid-August to early September, with spawning occurring from late September to early November. Juveniles emerge in spring and rear in freshwater for a few months before outmigrating in the late summer or early fall of their first year as sub-yearlings. Thus, fall Chinook salmon in the Toutle River system at the time of the May 18, 1980 eruption were likely limited to early life stages rather than adults. While there is little information on the survival of juvenile fall Chinook salmon in the Toutle River system immediately following the eruption, salmonids were found to persist in localized areas, especially those that were not affected by the debris avalanche. Based on returns of smolts released with coded-wire tags prior to the eruption, most returning adults in 1980 and 1981 strayed to other lower Columbia River and Cowlitz River tributaries at rates greater than before the eruption (Martin et al. 1984). However, some fall Chinook salmon that reared under pre-eruption conditions did return to the Toutle River system to spawn in 1981 (i.e., in Alder and Johnson creeks in the North Fork Toutle and South Fork Toutle subwatersheds, respectively). Although the subsequent survival to emergence of eggs from these spawners could not be determined, Chinook salmon fry from natural reproduction were observed during spring 1982 in at least two affected tributaries (i.e., in Deer and Elk creeks in the North Fork Toutle subbasin). The presumed survival of juvenile fall Chinook salmon in localized refugia immediately following the eruption and the return and successful spawning of adults that were at sea during the eruption represent two mechanisms by which the Toutle River fall Chinook salmon population was able to persist in the recent aftermath of the eruption.

Much of the fall Chinook salmon spawning areas in the mainstem Toutle, North Fork Toutle, and Green rivers were devastated as a result of the eruption (LCFRB 2004, WDW 1990). Brood stock collection was resumed in 1990 following renovations to the North Toutle Hatchery. Surplus hatchery fish were released upstream of the hatchery to spawn naturally. From 1951 to 1980, the Toutle River received plants of fall Chinook salmon from out of basin (WDFW 2004). After 1967, Toutle stock was primarily used, although Spring creek and Big Creek (1967), Kalama (1979) and Washougal and Kalama (1987) stocks were also used and beginning in 1985, introduced fish were obtained from the Cowlitz, Grays River, Big Creek, Kalama, and Washougal hatcheries. Currently, the hatchery relies on Toutle River Fall Chinook Salmon hatchery fish to meet the broodstock collection goals. The North Toutle Hatchery Fall Chinook Salmon Program is currently operated as an integrated harvest program and accounts for most fall Chinook salmon returning to the Toutle River system (LCFRB 2004). Hatchery produced adults currently make up the majority of natural spawners in the Green and North Fork Toutle rivers.

Hatchery and wild fall Chinook salmon in the Toutle River are part of the Lower Columbia River Chinook Evolutionary Significant Unit (ESU), which has been listed as threatened under the ESA since May 24, 1999 (NMFS 1999). In their Salmonid Stock Inventory (SaSI), WDFW does not specifically recognize fall Chinook salmon stocks in the mainstem and North Fork Toutle rivers, but does recognize the South Fork and Green River as separate stocks based on their spawning distribution (WDFW 2012). Both the South Fork and Green River stocks were rated as depressed during the 1992 status review. As of 2002, the South Fork stock remains depressed, but the Green River stock was upgraded to healthy. As an indication of long-term trends, Figure 4 shows the abundance of natural fall Chinook salmon spawners in the different subbasins of the Toutle River system. Following the eruption, spawner surveys for the Green River and South Fork Toutle River stocks were not resumed until the early 1990s; it is unclear whether surveys of the North Fork Toutle and mainstem Toutle rivers were not resumed or are included in the estimates for Green River and South Fork Toutle River stocks.

Currently, the distribution of spawning includes roughly 2.6 miles in the South Fork immediately upstream of the mainstem confluence and in the lower 0.6 miles of the Green River below the North Toutle Hatchery (LCFRB 2004). Toutle River fall Chinook salmon are reported to be re-establishing a population in the Toutle River system as the watershed becomes stabilized following the eruption (WDFW 2004, LCFRB 2004, USACE 2007). However, juvenile production from natural spawning is presumed to be low and a baseline risk assessment determined that fall Chinook salmon in the Toutle River system have a high to very high risk of extinction (LCFRB 2004, USACE 2007). During the 1990s, tule fall Chinook salmon stocks, such as the South Fork and Green River stocks, experienced poor survival (WDFW 2012). While the eruption had dramatic effects on habitat conditions, other factors such as ocean survival, harvest rates, and hatchery practices have also played a major role in the rehabilitation of Toutle River fall Chinook salmon. Portions of the basin (i.e., the South Fork) have been closed to sport fishing retention of Chinook salmon since the eruption, but sport fisheries in other tributaries as well as commercial and recreational fisheries in the ocean and Columbia River include the harvest of Toutle River fish. Coded-wire tag data from 1989 to 1994 indicate a 41% harvest rate for North Toutle Hatchery fall Chinook salmon (LCFRB 2004).

Recovery of fall Chinook salmon in the Toutle River system includes challenges associated with a large hatchery program, harvest, sedimentation, and other habitat issues. In the early to mid-2000s, estimates of natural spawners reached pre-eruption levels in the Green River and South Fork. However, much of this production is attributed to hatchery releases. Because hatchery juveniles are released as sub-yearlings, presumably as smolts based on size and condition (WDFW 2004), survival and production of these fish may not be heavily influenced by juvenile rearing habitat conditions in the Toutle River. Thus, while fall Chinook salmon have been re-establishing in the Toutle River system since the eruption and have been supporting natural reproduction, factors such as harvest and hatchery production confound comparison of current stock statuses compared to pre-eruption conditions. In terms of habitat for fall Chinook salmon in the Toutle River system, egg incubation is considered the most critical lifestage, which in turn, is thought to be limited primarily by sediment load and secondarily by channel stability (LCFRB 2004). Spawning is the second-most critical lifestage, and currently is thought to be limited by sediment load, habitat diversity, and temperature.

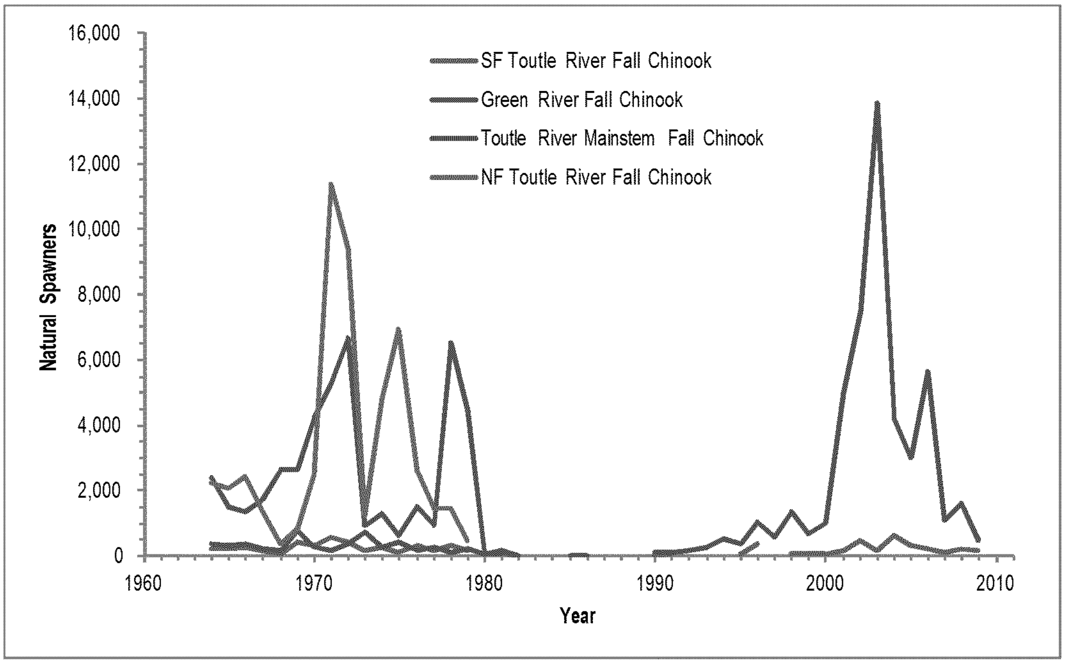

Figure 4 – Number of natural spawning fall Chinook salmon observed in basins of the Toutle River system from 1964 to 2009.

Source: WDFW 2012 (South Fork Toutle and Green rivers) and WDW 1990 (Toutle and North Fork Toutle rivers). Data are total escapement estimates based on annual peak live plus dead spawner counts over 5.7 miles (South Fork Toutle) and 0.6 miles (Green River) and include hatchery and natural origin spawners. Data from WDW 1990 are unspecified.

7.2 Toutle River Winter Steelhead

Winter steelhead were historically distributed throughout the Toutle River system, including the mainstem Toutle, North Fork Toutle, and South Fork Toutle rivers as well as the Green River (LCFRB 2004). Estimates of historic adult winter steelhead abundance in the North Fork Toutle and South Fork Toutle rivers range from 7,000 to 15,000 fish and from 4,000 to 4,500 fish, respectively. Based on estimates of historic habitat conditions in th e Toutle River system using the EDT model, WDFW estimated that the historic abundance of winter steelhead in the Toutle River system was 2,627 spawners in the South Fork Toutle River and 3,770 spawners in the North Fork Toutle River (Busack and Rawding 2003). Since 1953, hatchery-origin winter steelhead from Elochoman and Cowlitz rivers and Chambers Creek broodstock have been released in the North Fork Toutle River (LCFRB 2004). With the exception of small releases of winter steelhead fry following the eruption of Mount St. Helens, no hatchery winter steelhead have been released in the Green River or the South Fork Toutle River. Between 1968 and 1985, total winter steelhead hatchery releases were estimated to be 58,079 fish in the South Fork Toutle River. The Toutle River system is not known to have had a native summer steelhead run, although hatchery summer steelhead from other stocks have been released in the North Fork Toutle River since at least 1970.

Adult winter steelhead return to the Toutle River system to spawn from December through April, and spawning generally occurs from March to early June (LCFRB 2004). Juveniles generally rear in freshwater for two years and outmigration occurs from April to May with a peak in early May. One year after the eruption in the spring of 1981, smolt trapping in a mudflow-impacted tributary to the North Fork

Toutle River (i.e., Deer Creek) revealed that juvenile steelhead in the stream prior to the eruption had survived to smoltification (Martin et al. 1981). Juveniles were also observed in other mudflow-impacted tributaries in the North Fork Toutle River (i.e., Wyant Creek) and South Fork Toutle River subbasins (i.e., Johnson and Herrington creeks; Martin et al. 1984). In addition, some steelhead that reared under pre-eruption conditions returned to the Toutle River system to spawn in 1981 (Martin et al. 1981, Martin et al. 1984). Returning adults and/or redds were observed in tributaries to the North Fork Toutle River (i.e., Deer and Wyant creeks) and South Fork Toutle River (i.e., Johnson Creek; Martin et al. 1984).

Naturally-produced winter steelhead in the Toutle River system are part of the Lower Columbia River Steelhead Distinct Population Segment (DPS), which was listed as threatened under the ESA in March 1998. Naturally-produced summer steelhead are also included in this DPS. Unlike many other winter steelhead stocks in the Lower Columbia River DPS, the South Fork and North Fork Toutle rivers have few hatchery fish spawning in natural spawning areas (Good et al. 2005). Perhaps as a result of this, the North Fork Toutle River is the only population in the DPS analyzed by the National Marine Fisheries Service (NMFS) with a positive long-term population trend based on the abundance from 1990 to 2002.

WDFW (2012) recognizes three separate winter steelhead stocks in the Toutle River system based on their distinct spawning distributions. South Fork Toutle Winter Steelhead spawn in the South Fork Toutle River mainstem and its tributaries such as Studebaker, Johnson, and Bear creeks. This stock was rated as healthy in the 1992 status review but was downgraded to depressed in 2002 due to chronically low escapements since 1994. The Mainstem/North Fork Toutle Winter Steelhead stock includes the mainstem and North Fork Toutle rivers as well as tributaries such as Alder and Deer creeks. This stock was rated as depressed in both 1992 and 2002 due to chronically low escapements. The Green Winter Steelhead stock includes the Green River and its tributaries such as Devil, Elk, and Shultz creeks. This stock was also rated as depressed in both 1992 and 2002 due to chronically low escapements. All three stocks are managed for natural production and are of native origin. As an indication of long-term trends, Figure 5 shows the abundance of natural winter steelhead spawners for the different stocks of the Toutle River system.

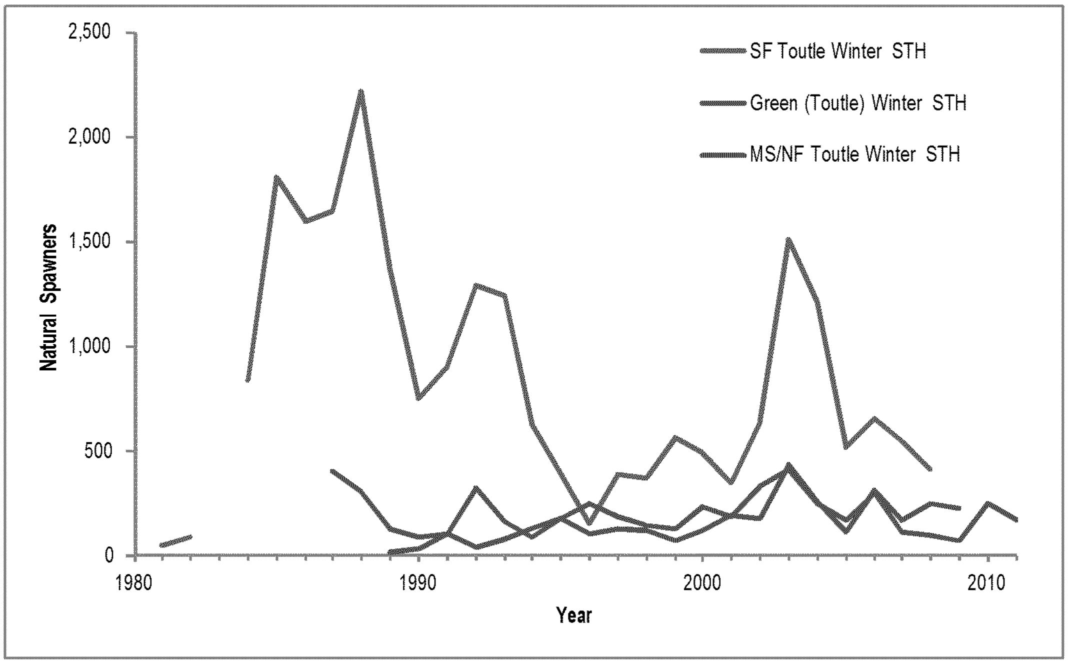

Figure 5 – Number of natural spawning winter steelhead observed in basins of the Toutle River system from 1981 to 2011.

Source: WDFW 2012. Data are trap counts from the North Toutle Fish Collection Facility (Toutle and North Fork Toutle rivers) and index escapement estimates based on redd counts in subbasin mainstem and tributary index sites (South Fork Toutle and Green rivers).

In the North Fork Toutle River, returns from 1991to 1996 were believed to be composed entirely of natural-origin fish; hatchery-origin fish are believed to contribute little to natural production of winter steelhead (LCFRB 2004). As of 2010, Toutle River winter steelhead is considered a 'core' population that must be returned to a high level of viability if the Lower Columbia Winter Steelhead DPS is to persist; the current viability is low (AMEC 2010).

The greatest potential limiting factor for winter steelhead recovery in the Toutle River is tributary habitat quality and quantity (LCFRB 2004). Habitat for winter steelhead egg incubation is the most critical life stage that is thought to be limited by sediment load, temperature, and channel stability (LCFRB 2004). Age 0 summer rearing is the next-most critical lifestage, and is limited primarily by numerous factors including: habitat diversity, flow, pathogens, sediment load, temperature, channel stability, competition with hatchery fish, food, and predation.

8. Summary

Information gained from the suite of fish, habitat, and ecology studies implemented after the 1980 eruption of Mount St. Helens provide a unique opportunity to investigate how ecosystems and species respond to and recover from major disturbances. Even with the extensive environmental disturbance that occurred within the Toutle River, aquatic habitats and fish populations began working toward recovery within a year post-eruption. Survival, recolonization, and subsequent successful reproduction of fish in the Toutle River basin were key factors in the re-establishment of fish populations over time. Biological and ecological processes and interactions, such as aquatic habitat recovery, primary productivity, thermal regulation, prey availability, and competitor/predator interactions, have also played a role in shaping the recovery of fish populations within the basin. Furthermore, fisheries management actions, such as stocking and a sport fishery harvest moratorium, likely contributed to the re-establishment of both stream- and lake-dwelling populations.

Although fish populations have experienced substantial growth in localized stream reaches and lakes within the Toutle River basin, populations have not yet rebounded to pre-eruption levels. Land use and fisheries management practices continue to present limitations for the recovery of anadromous fish populations in the North Fork Toutle River and the mainstem Toutle River. As summarized in the Lower Columbia Subbasin Plan (LCRFB 2004), decades of natural processes combined with ongoing human activity in the Toutle River Basin have altered watershed processes and continue to impact the quality and quantity of habitat needed to sustain viable populations of salmon and steelhead.

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Ms. Simon has 9 years of experience in biological and environmental sciences. Her background is aquatic ecology, particularly with regards to understanding relationships among aquatic habitat characteristics and various freshwater taxa (e.g., fish, amphibians, macroinvertebrates). Jude's field experience includes aquatic habitat and wildlife surveys, biological monitoring and evaluations of fish passage conditions for ESA-listed species, instream flow field studies, wetland delineations, and water and sediment quality sampling. In addition, Jude offers a combination of strong interpersonal skills and an attention to detail that makes her ideally suited for data collection, QA/QC, management, and analysis roles, as well as technical writing and reporting. For the Pebble Project in Iliamna, Alaska, she has led an extensive formal QA/QC of over 40 databases, encompassing 8 years of fish and aquatic habitat data, and has been a key team member in preparing several chapters, appendices, and technical reports describing the methods and results of the comprehensive fish and aquatic habitat studies conducted for the Pebble Project. Ms. Simon has conducted fisheries-related field work in South Central Alaska and in Washington, Oregon, Idaho, and New Mexico.

Danielle F Evenson

Ms. Evenson is an Interdisciplinary fishery scientist with over 16 years of professional experience specializing in analysis of complex fisheries datasets for management applications and policy development. Particular interests include improving stock assessment methods, innovation in fisheries management, fish ecology, management applications of fish genetics, adaptive approaches to natural resource management, and building capacity among tribal organizations to manage fisheries. She has a track record for building comprehensive fishery research programs to address questions of interest to resource management. In addition to her technical abilities, Ms. Evenson is known for creative problem solving and fostering collaborative relationships among management agencies and competing resources users. She is particularly effective at bridging gaps between science and policy. Previously, Ms. Evenson directed research activities associated with the salmon, crab, herring, whitefish, and lamprey resources of the Arctic-Yukon-Kuskokwim (AYK) region for the Alaska Department of Fish and Game and served as a quantitative fisheries scientist for the Columbia River Inter-Tribal Fish Commission focusing on stock assessments of mid-Columbia Chinook salmon.

MaryLouise Keefe, Ph.D.

Dr. Keefe has managed complex environmental projects and coordinated multidisciplinary teams throughout the Pacific Northwest for 26 years. She has worked on 16 complex water development projects throughout the US and in Canada and has managed large aquatics or multidisciplinary teams on a dozen of them.. Dr. Keefe has written dozens of study plans, technical reports, FERC exhibits and supporting federal permits, has published several papers in professional journals, and contributed chapters to books. Dr. Keefe received her Ph.D. in Biological Sciences from the University of Rhode Island in 1989. Her research on the use of chemical signals in native brook trout populations was a seminal work in chemical ecology, as it was the first to demonstrate the ability of juvenile salmonids to differentiate piscivorous from non-piscivorous predators using chemical signals. After completing her education, Dr. Keefe spent the next 7 years leading a research program focused on natural production of Chinook salmon and steelhead in the Grand Ronde River basin for the Research Section of Oregon Department of Fish and Wildlife. While in Eastern Oregon, she also was Adjunct Faculty at Eastern

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Timothy Sullivan

Mr. Sullivan is a fisheries biologist with more than 11 years of experience conducting laboratory and field evaluations of fish passage and protection technologies, fish habitat and population assessments, instream flow assessments, upstream passage barrier assessments, and fish tracking studies using various telemetry methods. He has participated in all aspects of fisheries studies including study design, implementation, data analysis, and reporting. Mr. Sullivan earned an M.S. in Fisheries and Wildlife Conservation (2004) from UMass, Amherst evaluating upstream passage of American shad on the Connecticut River, and a B.A. in Biology (1997) from Colby College in Waterville, Maine.